AIR QUALITY TRENDS IN ONTARIO

1971 - 1979

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Ministry
of the
Environment

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With the passage of the Air Pollution Control Act (1967), the Province of Ontario embarked upon a program of emission source regulation to meet the desirable ambient air quality criteria set forth in the Act. To document the effectiveness of emission regulation, an extensive network of ambient air monitors was established across the Province. Through the years, the network has evolved and been modified in response to the needs of the monitoring program.

From the data collected during the period 1971 to 1979, concentration trends for eleven pollutants have been determined and are presented in this report. In addition, comparisons of data are made with the appropriate desirable ambient air quality criteria and are also reported herein.

1. The Ontario Air Quality Monitoring Network

The regular monitoring of atmospheric pollutants began in Ontario in the early 1960's in the Metropolitan Toronto area. With the passage of the Air Pollution Control Act of 1967, the task of air pollution control was centralized in an agency of the provincial government. At that time, the monitoring program began its expansion across the Province. By the time of the enactment of The Environmental Protection Act in 1971, the number of monitoring instruments had reached 339 for continuous monitoring of gases and total suspended particulate matter. By 1979 the number of instruments was 534 (Figure 1), a growth of 58% in the monitoring network.

The number of monitoring instruments reported in Table 1 reflects the existence of a sensor at a site for a given time in that year. Because of the fluid nature of the network, however, monitoring may begin and/or terminate during a particular year. In order to calculate an annual mean which is meaningful, a minimum number of samples must be collected. Therefore, for continuous gaseous monitoring and

soiling index, only those stations with 75% of the maximum possible hourly observations (8760 hours x 75% = 6570 hours) have been used for trend analysis and comparison with annual criterion. For total suspended particulate matter and particulate lead, stations must have 20 samples with at least 4 per season to be used for calculation of an annual geometric mean. All stations have been used for comparisons with hourly or daily criterion.

2. Ambient Air Quality Criteria in Ontario

The current Ontario criteria for desirable ambient air quality for seven of the eleven pollutants whose trends are discussed below are given in Table 2. As yet no criteria have been established for total hydrocarbons, nitric oxide, nitrogen oxides, or total reduced sulphur. A provisional guideline for total reduced sulphur of 27 ppb in the vicinity of kraft paper mills has been recommended. These criteria serve as a convenient yardstick by which the Province may estimate its success in achieving goals for desirable ambient air quality.

Ontario desirable ambient air quality criteria are based upon the examination of all known effects of the contaminant and are, in terms of time-concentration values, below a concentration known to have significant adverse effect on man, animals, vegetation, or property. The percentage of stations meeting each criterion is treated below by individual pollutant as is the total number of criterion exceedences.

3. Graphical Display of Air Quality Trends

The concentration trends for each of eleven pollutants are analyzed in this study. To visually present the information representing the distribution of air quality data, two graphical techniques are employed.

The first technique is the double-arrow plot which is employed for data years with 3 to 11 reporting stations. This technique is illustrated in Figure 2a. The double-arrow plot displays the maximum annual mean, ensemble average, and minimum annual mean concentration for the n stations reporting. The maximum and minimum are self explanatory. The ensemble average (a) is calculated by

$$a = \frac{1}{n} \sum_{i=1}^{n} m_i \qquad (1)$$

where m_i is the annual mean of the i th station, n is the number of stations and indicates the summation of all m_i from 1 to n.

The second display technique is known as the box plot. The plotting convention for the box plot is displayed in Figure 2b. For a given pollutant, the annual mean of all eligible stations are grouped and then ranked. From this ranking, the 10, 25, 50 (median), 75, and 90 percentile levels are determined. These indicate the percentage of stations cleaner than the plotted value. For example, if the 25 percentile is 17 units, 25% of the stations measuring this pollutant have an annual mean less than 17 units. The ensemble average of the stations (equation 1) in a given year is also plotted. The box plot is used whenever 11 or more stations report means in a given year.

The 10 and 25 percentiles typify the trend of the "cleaner" sites in the sample. The average and median may be thought of as depicting average sites, while the 75 and 90 percentiles typify the "dirtier" sites - those with the highest annual means. Note, however, that these descriptive terms refer only to the distribution of sites within the sampling network for that pollutant, and "cleaner" or "dirtier" sites may exist elswhere.

4. Statistical Analysis of Trend

For each of the eleven pollutants, the average concentration trend for the network is determined using those stations with valid averages in each of the two years in question. The network trend is based upon whether the average concentrations at more stations are either increasing or decreasing between the chosen pair of years. The trend is tested to determined whether the trend was due to random variation or not by the non-parametric Wilcoxon Matched-Pairs, Signed-Ranks Test (See Appendix A). A high confidence level (≥95%) indicates the trend was not likely due to random variations. With a confidence level less than 95%, the trend is considered as having "no change". A minimum of 6 stations with valid annual averages is required to apply the test.

The trend analysis used in this report is designed to show changes in the provincial network as a whole. Trends (or the lack of trends) in the network data do not imply that the concentrations for a station or city follow a similar trend. Trends for stations or individual cities are beyond the scope of this study.

It should be noted that the trend analysis can only be applied to those stations which report valid annual means in each of the given years. When the network changes the number of its stations significantly, the possibility arises that the calculated trend may differ from that apparent in the percentile distributions for the two years.

5. Total Suspended Particulate Matter Trends in Ontario

Total suspended particulate matter (TSP) has many sources both natural and man-made. Traditionally, air pollution has been identified as black or dark smoke by the public. Improved combustion technology and a switch to cleaner fuels has eliminated black smoke as a major pollutant. Fine particles of smoke from combustion and dust from construction, mining, metal smelting and processing, grinding processes, and transportation constitute much of man's contribution to TSP. Natural sources include forest fires, wind-blown soil, and volcanoes. The smaller particles are capable of travelling many thousands of kilometers by moving within large masses of air.

Measurement of TSP in Ontario is by the standard high-volume sampling technique. This method collects particles with diameters between 0.1 and 50 micrometers over a 24-hour period. Sampling rates vary in Ontario. Stations sample either daily, once every three days, or once every six days. The annual geometic mean is used in the trend and distribution analyses rather than the arithmetic mean.

The box plot of the history of TSP concentrations shows a substantial decrease in all plotting positions between the years 1973 and 1975. The TSP trend of the median of annual geometric means decreases annually from 1971 to 1978 and then increases in 1979. Other plotting levels indicate a general decrease from 1971 to 1975 with a leveling off from 1975 to 1978 at all but the 90 percentile. 1979, in contrast, shows an increase at all percentiles except the 90 percentile. Trend analysis of annual geometric means indicates that there has been a decrease in the network each year from 1971 to 1978 (Table 3) and that trend has been significant at greater than or equal to a 95% confidence level except for the periods 1972 to 1973 and 1977 to 1978. In 1978 -1979, the increase was significant at the 99% confidence level. The decrease in TSP over the period 1971 to 1979 was greater than 24% for all percentiles.

Air quality criteria for TSP are based upon daily and annual means. The percentage of stations meeting the annual criterion of 60 ug/m ^{3} (geometric mean) is shown in Figure 4a. In 1971, only 11% of the stations met the annual criterion. By 1979, however, 44% were less than the maximum desirable level. The percentage of stations meeting the 24-hour criterion (120 ug/m^3) increased from 4% in 1971 to 15% in 1979 (Figure 4b). Natural sources and long-range transport of particulate matter are significant contributors to measured TSP. Daily levels can, therefore, be significantly influenced by meteorological factors such as precipitation and wind speed, and thus, it is not surprising to see large fluctuations in the number of daily TSP values exceeding the criterion from year to year. During the period of study, for example, the average number of exceedences per station varied from a maximum of 20.1 in 1974 to a minimum of 10.9 in 1977.

6. Soiling Index Trends in Ontario

The soiling index (SI) is a relative measure of suspended particulate matter in the 0.1 to 10 micrometer size range and is based upon the optical transmission density of the particulate matter deposited on the filter. The measure, therefore, is related not only to the amount of particulate matter but also to its physical properties such as opacity. The unit of measure is the Coefficient of Haze (COH) per 1000 feet of air sampled. Data are averaged over one or two hours. The one-hour average SI is connected to the Ontario real-time data acquisition system whereas the two-hour average SI is not. Studies have shown that the two methods are not strictly comparable. Therefore, for the purpose of trend analysis, the one and two hour data are reported separately. The two have been combined, however, when determining criteria exceedences.

The trend of 2-hour soiling index (Figure 5) indicates a distinct decrease over the 1971 to 1979 period for all percentiles amounting to 35% or more. Year-to-year variations were more erratic, however, resulting in only 4 of the 8 year-pairs showing a significant trend downward for the network average at greater than the 95% confidence level or higher. (Table 4).

Close examination of the data also reveals an apparent contradiction between the percentile levels and the network trend analysis for the period 1975-1976. In the 1975-1976 period, the number of stations increasing is three times greater than the number

decreasing. The percentiles for these two years show, however, a decrease at all but the 25 percentile. This contradiction is due to the change in the network size in the two years. In 1975, 24 stations reported valid annual averages; in 1976 this number increased to 31. The number of stations that reported valid annual averages in both years, however, was only 20. Within these 20 stations, 15 showed an increase while 5 decreased although the changes were not sufficient to state a confidence of 95% or greater in the trend, and therefore there was "no change" in the trend. The 1-hour soiling index history (Figure 6) shows a variation at all percentiles without a definite trend.

The 24-hour average criterion of 1.0 COH/1000 ft was met at 50-68% of the soiling index monitors (Figure 7a). The percentage of stations meeting the annual average criterion for soiling index of 0.50 COH/1000 ft varied from 87% to 97% between 1971 and 1979 (Figure 7b).

7. Sulphur Dioxide Trends in Ontario

Over one half of Ontario's sulphur dioxide (SO_2) emissions are from the primary smelting of nickel, copper, and iron in the Sudbury and Wawa areas. Thermal generating stations are the largest sources of SO_2 in southern Ontario. The remaining SO_2 is emitted by industrial, commercial, and residential fuel users as well as refineries, coke ovens, and other industrial operations. It should be noted, however, that community air quality is, on the long term, affected more by, nearby sources often emitting at low elevation than by large and distant sources emitting from tall stacks.

Sulphur dioxide concentrations in Ontario have shown a decrease in the percentiles ranging from 50% to 85% (Figure 8) over the 1971-1979 period. The network trend in annual average concentration decrease significantly at 95% or greater confidence in five of the eight periods. In 1975-1976, the trend was upward at the 95% confidence level (Table 5). The largest decreases in the median value came between 1972 and 1973 (30%) and 1973 and 1974 (29%).

The percentages of stations meeting the SO_2 criteria of 0.25 ppm for a 1-hour average, 0.10 ppm for a 24-hour average and 0.02 ppm annual average are shown in Figure 9. In 1971 and 1972 less than one-half of the stations met the annual criterion. Since 1977, over 90% have met that criterion. The number of stations meeting the 24-hour and 1-hour criterion have also increased (Table 5). The total number of times the criteria were exceeded has dropped despite an increased in the number of monitors. In 1971, 52 monitors exceeded the 24-hour criterion a total of 251 times. In 1979, the exceedences dropped to 38 despite an increase in monitors to 81, a decrease of 85% in the number of exceedences and an improvement of 31% in the percentage of stations meeting criterion. The one-hour criterion was exceeded 2018 times in 1971 but only 635 times in 1979, a decrease of 69% despite a 56% increase in the number of stations. There was also a 26% improvement in the percentage of stations meeting this criterion.

8. Carbon Monoxide Trends in Ontario

In terms of total weight and concentration, carbon monoxide leads all other contaminants in city air. Mobile sources, trucks and automobiles, are almost exclusively responsible. Although pollution control equipment has reduced the output per car, the increase in the number of vehicles on many streets has limited the overall reduction.

The trend in CO in Ontario (Table 6) must be broken into two parts. Prior to 1976, there were less than 10 monitors with sufficient data to calculate on annual average in the Province while from 1976 to 1979 there were 16-21 such monitors in service. The first period plotted with the double-arrow technique (Figure 10) shows a decrease in all levels after 1973. The 1975 average of the annual means for the network was almost half of the 1973 average. From 1976 to 1979, the network average was slightly below the 1975 average concentration and remained constant for four years. Percentiles showed some variability but no definite trend. The network trend analysis shows that any year-to-year trend was too small to be significant at 95% confidence (Table 6).

Stations meeting the 8-hour criterion of 13 ppm have increased from 65% in 1971 to 86% in 1979 while the total number of exceedences increased from 30 to 57. This

figure is slightly misleading, however, since 55 of the 57 exceedences in 1979 (as well as all of those in 1977, 32 of the 34 in 1972, and 47 of 48 1979 exceedences) occurred at a station located within 4 meters of the street in downtown Toronto.

The 1-hour criterion of 30 ppm has been met at almost all sites (Table 6). The above mentioned Toronto location has measured 85 of the 87 exceedences in the 1971-1979 period.

9. Trends of Total Hydrocarbons in Ontario

Hydrocarbon sources include emissions from automobiles and petroleum producing and handling facilities as well as from natural sources such as trees and other vegetation. Two types of measurements are made of hydrocarbons in Ontario. The first uses flame ionization techniques to measure all hydrocarbons and is reported as total hydrocarbons. Methane, however, does not participate in a number of photochemical reactions which form oxidants. Thus, measurements have also been made with the methane fraction removed, and the resulting hydrocarbon measurement is refered to as reactive hydrocarbons. Reactive hydrocarbon measurements began at a few selected sites in 1976, and not enough data exists for determination of trends. No criteria have yet been established for reactive or total hydrocarbons.

Since the number of total hydrocarbon monitors has varied around 10 for the 1971-1979 period, the trend history (Figure 11) has utilized the double-arrow method only. The average of the annual means shows no definite trend oscillating between 2.10 and 1.90 ppm.

10. Trend of Ozone in Ontario

Ozone is a naturally occurring constituent of the upper atmosphere. In the lower atmosphere, it is generally a secondary product of photochemical reactions among reactive hydrocarbons and nitrogen oxides. In the upper atmosphere, ozone plays an important role in the maintenance of life on the ground by absorbing harmful ultra-violet radiation. In the lower atmosphere, however, ozone is detrimental to the health of man and plants as well as enhancing damage to various materials.

Since time is needed for the afore-mentioned photochemical reactions to be completed, ozone is often found some distance from the source of its pollutant precursors. Thus, high concentrations of ozone which occur at rural location are not indicative of natural or local sources but the transport and reaction in the presence of adequate sunlight of the ozone precursors from the upwind urban sources.

In 1973, a monitoring instrument using chemiluminescence methods to measure ozone specifically became available. During 1974, there was a change in the Ontario monitoring network from oxidants to ozone. Therefore, the trend analysis begins with the year 1974. There is a large variation in year-to-year concentrations (Figure 12) but no definite trend. Indeed, the statistical analysis of network trend (Table 8) indicates that there was a significant increase during 1977-1978 (98% confidence), a significant decrease during 1978-1979 (99%) and 1975-1976 (98%), and no significant change during 1974-1975 and 1976-1977.

Since ozone formation is very dependent upon weather conditions, as is the transport of ozone formed from precursors emitted at distance, differences from year to year will reflect weather variations as well as changes in precursor emissions. Ozone is also seasonally dependent with highest concentrations occurring during the spring and summer.

Exceedences of the 1-hour ozone criterion of 80 ppb are frequent, their annual total being dependent also on weather conditions. Only in 1974 did the number of stations meeting the criterion exceed 20% (Table 8). This figure is somewhat misleading since many of the stations were installed after the summer season when hourly concentrations are at their peak.

11. Trend of Nitrogen Oxides in Ontario

The oxides of nitrogen (NO and NO_2) are generated by natural as well as anthropogenic sources. Nitrogen and oxygen, which are the principal constituents of the atmosphere, combined during high temperature combustion to form nitrogen oxides. The main sources are automobile exhausts, power plants, incinerators and chemical processes. Lightning and soil bacteria are the main source of natural nitrogen oxides in the lower atmosphere.

No evidence exists that nitric oxide (NO) at the concentrations measured in the atmosphere has any direct adverse effect on health and welfare.

Oxidation of nitric oxide to nitrogen dioxide (NO_2), however, does occur, and nitrogen dioxide is known to affect health as well as visibility. The nitrogen oxides also play an important role in the photochemical reactions involving ozone and other oxidants. Nitrogen oxides have also been implicated in the acidification of precipitation.

Although there has been some form of measurements of nitrogen oxides since 1971, the trend analyses commence with the 1974 data when monitoring by chemiluminescence techniques was begun. Data taken earlier with other methods are not strictly comparable with present analysis techniques.

There is a general downward trend in average NO_2 concentrations over the 1974 to 1979 period (Figure 13) although only two of the two-year periods showed a network trend downward at 95% confidence (Table 9). Most stations meet the daily NO_2 criterion of 0.10 ppm and and hourly criterion of 0.20 ppm (Table 9).

The nitric oxide monitoring network was established in 1974 and doubled in size in the 1976-1979 period. There is a decreasing trend in the 90 percentile, the network average, and the 10 percentile but no apparent trend for other plotting positions (Table 10, Figure 14). The only period when there is a significant trend is during 1977-1978: downward at 98% confidence (Table 10). No criteria have been set for NO.

Nitrogen oxides (NO_x), essentially the sum of NO and NO_2, show a downward trend at all plotting for the period 1977 to 1979 (Figure 15). The downward trend for the network average was significant at the 95% confidence level for the 1977-1978 and 1978-1979 periods (Table 11). The trend had been upward and significant for the period 1976-1977.

12. Trend of Total Reduced Sulphur in Ontario

The first extensive monitoring of total reduced sulphur (TRS) began in Ontario in 1976. Most of the total reduced sulphur compounds may be found in the form of hydrogen sulphide. In the vicinity of pulp and paper mills and refineries, however, significant concentrations of mercaptans and other reduced sulphurs may be present.

From the double-arrow plots (Figure 16) there is no apparent trend in the

network average, a fact substantiated by the trend analysis (Table 12) which showed no significance in trend at 95% confidence or greater in the one period with enough stations to apply the statistical test.

13. Trend of Particulate Lead in Ontario

Much of the particulate lead found in the atmosphere has been released in the combustion of gasoline containing lead additives. Other sources of lead include the secondary smelting of lead, battery manufacture, metal fabrication (brass, bronze, and solder), some paint and glass manufacture, and the production of iron, steel, copper, and nickel. Since 1972, there has been a reduction in the lead content of leaded gasoline and in 1975, unleaded gasoline was introduced; the effect of these two actions has reduced the 1979 emission of lead from automobiles by 68% as compared to 1970 levels.

Lead concentrations showed a slight rise from 1971 to 1974 followed by a significant decline from 1974 to 1979 (Figure 16). These changes follow closely the total amount of lead consumed in Ontario due to gasoline usage (Table 13). The average lead concentration of all stations except those surrounding lead-processing plants and the consumption of lead through gasoline usage were highly correlated with a correlation coefficient of 0.97, nearly perfect correlation.

The network trend showed most periods with a significant downward trend at 99% confidence (Table 13). Only the periods 1972-1973 and 1975-1976 were not significant at 95% or greater confidence.

The criterion for lead is 5.0 ug/m^3 for a 24-hour concentration. The percentage of stations meeting this criterion on all monitoring days has been about 80% for all years except 1973-1975 (Figure 17) - the peak years of lead emissions from gasoline usage. The total number of occasions that the criterion was exceeded has been decreasing since 1974 despite an increase in the number of monitors - a 35% decrease in exceedences and a 36% increase in network size. Much of this reduction can be attributed to controls imposed on emissions from lead processing plants.

14. Ontario's Air Pollution Index

An Air Pollution Index (API) based upon the 24-hour average concentration of

sulphur dioxide and suspended particulate matter has been in use in Ontario since March 1970. Air Pollution Index stations were established in Toronto and Hamilton in 1970, Sudbury and Windsor in 1971, Welland and Niagara Falls in 1974, Coniston in 1975, New Sudbury in 1976, Sarnia in 1977, and St. Catharines in 1979. The station opened in Happy Valley in 1971 was discontinued in 1975, and the Welland station was closed in 1978. The API at all stations have a common base; at an API of 32, the desirable air quality criteria for sulphur dioxide and soiling index on a 24-hour average are exceeded. When the API exceedes 57, health effects may increase in incidence, especially for the elderly and those with respiratory problems.

At an API of 32 with adverse weather conditions expected for the next 6 hours, suspected offending industries are alerted and may be asked to cut-back on their operations. At an API of 50 with adverse conditions expected for 6 hours, the Minster may order curtailment of industrial operations, and a shut-down may be ordered by the Minster if the Index exceeds 100.

The history of the Index stations, the maximum level and the number of periods during which the Index equalled or exceeded 32 and 50 for the years 1971 to 1979, is given in Table 14.

While the API is designed as a control measure to be utilized when adverse weather conditions cause prolonged elevated concentrations of particulate matter and SO_2 and is, therefore, very dependent upon weather and climatic fluctuations, the influence of source emissons control is also evident, especially in the cities of Toronto, Sudbury, Windsor, and Welland. Except for 1979 when unusual weather conditions prevailed, Hamilton has also shown a significant reduction in the number of occasions when the API exceeded 32.

15. Summary

Air quality in Ontario has shown a significant improvement over the years 1971 to 1979 for total suspended particulate matter, particulate lead soiling index, sulphur dioxide, and carbon monoxide. Much of this reduction can be attributed to emission source regulation during the mid-1970's. In the past few years, pollutant concentrations have fluctuated in response to changes in weather and climate as much as to changes in emissions.

Total suspended particulate matter decreased 32% over the 1971-1979 period. Decreases of 44% for 2-hour soiling index, and 57% for carbon monoxide were also found for this period as was a decrease in particulate lead of 45%. Sulphur dioxide concentrations were reduced by 68% in the 1972 to 1979 period.

Decreases of less than 20% were found for ozone, nitrogen dioxide, and nitrogen oxides for the 1975 to 1979 period.

The number of stations meeting the Ontario criteria for desirable air quality has increased over the period of study. In addition, the total number of exceedences of short term criteria has decrease for many pollutants despite an increase in the number of monitoring stations.

The Ontario monitoring network has grown and been modified over the 1971-1979 period in response to the needs for air quality surveillence across the province. There has also been and continues to be an increase in the number of chemical species monitored.

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TABLE 1

ONTARIO AIR QUALITY MONITORING NETWORK 1971 TO 1979

Number of Monitoring Locations Across Ontario

Pollutant

Year	TSP	Lead	SO_2	Soil	O_X	O_3	CO	TRS
1971	88	85	52	54	11	0	17	0
1972	105	27	49	57	8	0	19	0
1973	109	45	47	49	9	2	11	1
1974	129	55	51	52	7	13	13	2
1975	143	78	55	59	0	16	15	9
1976	142	89	67	64	0	19	18	10
1977	146	72	72	65	0	25	20	11
1978	155	92	80	69	0	28	22	12
1979	159	75	81	60	0	31	21	12

Year	NO_2	NO	NO_X	THC	RHC	CH_4	Total
1971	0	0	16	16	0	0	339
1972	12	0	17	16	0	0	310
1973	20	0	6	16	0	0	314
1974	18	4	9	18	0	0	369
1975	22	13	18	17	0	0	445
1976	20	18	19	18	4	0	478
1977	23	20	21	17	4	0	496
1978	25	21	23	16	4	0	547
1979	25	24	24	13	7	2	534

Legend: TSP - total suspended particulate matter; Lead - lead in suspended particulate matter; SO_2 - sulphur dioxide;

Soil - soiling index; O_x - oxidants; O_3 - ozone; THC - total hydrocarbons; RHC - reactive (non-methane) hydrocarbons; CH_4 - methane;

CO - carbon monoxide; NO_2 - nitrogen dioxide; NO - nitric oxide; NO_x - nitrogen oxides;

TRS - total reduced sulphur (expressed as hydrogen sulphide).

TABLE 2

Desirable Ambient Air Quality Criteria in Ontario

Name of Contaminant	Unit of Measurement	Average Amount of Concentration	Period of Time
Carbon Monoxide	parts of carbon monoxide per one million parts of air by volume	30 13	1 hr. 8 hr.
Nitrogen Dioxide	parts of nitrogen dioxide per one million parts of air by volume	0.20 0.10	1 hr. 24 hr.
Ozone	parts of ozone per one billion parts of air by volume	80	1 hr.
Soiling Index	Coefficient of Haze per 1000 feet of air	1.0 0.5	24 hr. 1 yr.
Sulphur Dioxide	parts of sulphur dioxide per one million parts of air by volume	0.25 0.10 0.02	1 hr. 24 hr. 1 yr.
Total Suspended Particulate Matter	micrograms of suspended particulate matter per cubic meter of air	120 60 (geom. mean)	24 hr. 1 yr.
Lead in Suspended Particulate Matter	micrograms of particulate lead per cubic meter of air	5.0	24 hr.

above abstracted from Ontario Regulation 872/74

TABLE 3

Total Suspended Particulate in Ontario 1971-1979
(Unit: micrograms per cubic meter - ug/m^3)

Year	No. of Stations*	Network Average	Percentiles 10	25	50	75	90	% Meeting Annual Criterion	No. of Stations	% Meeting 24-hour Criterion	Total Exceedences 24-hour Criterion
1971	54	95	59	69	85	118	136	11	88	4	1350
1972	71	96	52	68	83	113	148	16	105	13	1559
1973	69	90	56	67	82	104	137	17	109	8	1848
1974	96	76	43	58	71	88	106	28	129	14	2590
1975	99	65	37	50	65	76	89	41	143	15	1845
1976	109	64	39	47	62	76	90	47	142	13	2177
1977	115	61	37	46	57	70	103	57	146	17	1592
1978	121	59	37	42	55	71	106	57	155	16	1821
1979	129	65	38	48	64	76	94	44	159	15	2138

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	17	31	4	Down	95%
1972-1973	23	34	3	No Change	<95%
1973-1974	7	55	2	Down	99%
1974-1975	8	74	2	Down	99%
1975-1976	36	48	6	Down	98%
1976-1977	29	72	3	Down	99%
1977-1978	46	52	7	No Change	<95%
1978-1979	90	22	1	Up	99%

*Stations with sufficient number of samples to meet the following criteria for determining valid annual geometric mean: more than 20 samples per year with at least 4 samples per season.

TABLE 4

Soiling Index in Ontario 1971-1979

(Unit: COH/1000 ft.)

	2-Hour Sampling Rate							1-Hour Sampling Rate						
			Percentiles							Percentiles				
Year	No. of Stations*	Network Average	10	25	50	75	90	No. of Stations*	Network Average	10	25	50	75	90
1971	27	.32	.23	.25	.29	.36	.43	4	.52	(.26	minimum)		(.67	maximum)
1972	26	.33	.20	.25	.29	.35	.47	11	.32	.11	.13	.32	.37	.43
1973	25	.30	.17	.20	.24	.38	.44	10	.31	(.08	minimum)		(.48	maximum)
1974	29	.30	.18	.22	.29	.33	.42	11	.38	.06	.07	.30	.46	.54
1975	24	.25	.15	.17	.23	.29	.36	12	.38	.14	.15	.31	.43	.44
1976	31	.24	.13	.18	.23	.28	.31	16	.37	.12	.26	.38	.47	.49
1977	36	.23	.16	.19	.21	.25	.31	16	.37	.10	.14	.34	.48	.54
1978	35	.21	.13	.16	.19	.24	.28	17	.39	.13	.24	.40	.44	.56
1979	25	.18	.11	.15	.16	.20	.28	19	.37	.12	.19	.32	.47	.61

Year	Number of Stations*	% Meeting Annual Criterion	Number of Stations	% Meeting 24-hr Criterion	Total Exceedences of 24-hr Criterion
1971	31	87	54	37	258
1972	37	92	57	54	198
1973	35	97	49	51	235
1974	40	92	52	50	241
1975	36	97	59	63	141
1976	47	96	64	59	178
1977	52	90	65	66	201
1978	52	90	69	68	208
1979	44	91	60	60	263

Trend Analysis

	Number of 2-hour Stations*					Number of 1-hour Stations*				
Period	Increasing	Decreasing	No Change	Network Trend	Confidence Level	Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	6	11	2	No Change	<95%	0	4	0	No Change	TNA
1972-1973	5	11	2	Down	95%	3	6	1	No Change	<95%
1973-1974	10	10	0	No Change	<95%	5	3	0	No Change	<95%
1974-1975	0	19	0	Down	99%	5	3	0	No Change	<95%
1975-1976	15	5	0	No Change	<95%	8	4	0	No Change	<95%
1976-1977	5	21	4	Down	99%	5	7	3	No Change	<95%
1977-1978	7	24	0	Down	95%	7	6	2	No Change	<95%
1978-1979	11	10	3	No Change	<95%	6	7	1	No Change	<95%

TNA - Test Not Applicable

*Stations with sufficient number of samples (6570 for 1-hr; 3285 for 2-hr) to determine valid annual mean.

TABLE 5

Sulphur Dioxide in Ontario 1971-1979

(Unit: parts per million-ppm)

Year	No. of Stations*	Network Average	Precentiles 10	25	50	75	90	% Meeting Annual Criterion	No. of Stations	% Meeting 24-hour Criterion	Total Exceedences 24-hour Criterion	% Meeting 1-Hour Criterion	Total Exceedences 1-hour Criterion
1971	8	.038	(.015	minimum)		(.065	maximum)	12	52	52	251	31	2018
1972	13	.025	.013	.015	.020	.025	.030	46	49	61	144	37	1286
1973	22	.015	.003	.008	.014	.017	.021	77	47	74	70	47	687
1974	34	.014	.003	.006	.010	.017	.022	82	51	69	98	37	1154
1975	39	.012	.004	.007	.011	.015	.020	87	55	71	63	45	864
1976	48	.013	.005	.008	.011	.016	.020	85	67	78	86	51	1140
1977	54	.011	.004	.006	.011	.015	.017	93	72	78	67	62	1015
1978	59	.009	.003	.005	.008	.012	.015	100	80	84	80	61	912
1979	59	.008	.002	.004	.007	.011	.015	98	81	83	38	57	635

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	1	5	0	No Change	<95%
1972-1973	3	8	0	Down	95%
1973-1974	9	6	5	No Change	<95%
1974-1975	11	15	4	No Change	<95%
1975-1976	21	10	6	Up	95%
1976-1977	12	29	4	Down	99%
1977-1978	7	36	9	Down	99%
1978-1979	10	29	12	Down	99%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 6

Carbon Monoxide in Ontario 1971-1979

(Unit: parts per million - ppm)

Year	No. of Stations*	Network Average	Percentiles 10	25	50	75	90	No. of Stations	8-hour Criterion % Stations Meeting	8-hour Criterion Total Exceedences	1-hour Criterion % Stations Meeting	1-hour Criterion Total Exceedences
1971	6	3.7	(2.4	minimum)	(6.0	maximum)		17	65	30	100	0
1972	2	4.4	(4.0	minimum)	(4.8	maximum)		19	84	34	95	5
1973	5	4.2	(2.2	minimum)	(8.6	maximum)		10	80	24	85	2
1974	6	2.8	(1.9	minimum)	(5.2	maximum)		13	85	6	100	0
1975	8	2.2	(0.9	minimum)	(4.8	maximum)		15	93	3	100	0
1976	16	1.6	0.7	1.0	1.4	1.8	1.9	18	100	0	100	0
1977	16	1.6	0.7	1.1	1.5	1.8	2.2	20	95	12	95	2
1978	18	1.6	0.3	0.9	1.5	1.9	2.2	22	91	48	95	50
1979	21	1.6	0.3	0.9	1.3	1.6	2.0	21	86	57	95	28

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	1	1	0	No Change	Test Not Applicable
1972-1973	0	1	0	No Change	Test Not Applicable
1973-1974	2	2	0	No Change	Test Not Applicable
1974-1975	0	3	1	No Change	Test Not Applicable
1975-1976	3	4	1	No Change	95%
1976-1977	6	5	4	No Change	95%
1977-1978	6	6	3	No Change	95%
1978-1979	5	11	1	No Change	95%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 7

Total Hydrocarbons in Ontario 1971-1979

(Unit: parts per million - ppm)

Year	No. of Stations*	Network Average	Network Minimum	Percentiles 10	25	50	75	90	Network Maximum
1971	5	2.10	1.73	-	-	-	-	-	2.54
1972	8	2.02	1.59	-	-	-	-	-	2.31
1973	12	2.00	1.59	1.59	1.75	1.92	2.12	2.15	2.78
1974	9	2.03	1.82	-	-	-	-	-	2.80
1975	11	2.01	1.65	1.65	1.80	1.87	2.19	2.21	2.29
1976	14	2.09	1.55	1.55	1.67	2.11	2.32	2.39	2.57
1977	11	1.93	1.23	1.23	1.60	1.87	2.17	2.22	2.35
1978	7	2.06	1.48	-	-	-	-	-	2.56
1979	9	1.92	1.32	-	-	-	-	-	2.30

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	2	3	0	No Change	Test Not Applicable
1972-1973	4	4	0	No Change	<95%
1973-1974	5	3	0	No Change	<95%
1974-1975	4	4	0	No Change	<95%
1975-1976	5	4	1	No Change	<95%
1976-1977	2	8	0	No Change	<95%
1977-1978	4	3	0	No Change	<95%
1978-1979	1	5	0	No Change	<95%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 8

Ozone in Ontario 1974-1979

(Unit: parts per billion - ppb)

Year	No. of Stations*	Network Average	Percentiles 10	25	50	75	90	No. of Stations	% Meeting 1-hour Criterion	Total Exceedences 1-hour Criterion
1974	5	19.7	(13.7	minimum)		(31.0	maximum)	13	23	826
1975	12	23.1	16.4	18.2	22.3	24.3	24.4	16	6	2747
1976	15	18.8	12.0	15.3	17.4	20.5	22.9	19	0	1849
1977	18	20.8	11.3	16.6	19.5	22.1	26.5	25	16	1906
1978	21	22.3	12.7	17.3	19.2	27.6	29.3	28	7	3716
1979	23	18.7	11.0	14.4	17.2	23.2	25.9	31	6	1540

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1974-1975	5	0	0	No Change	Test Not Applicable
1975-1976	2	9	0	Down	98%
1976-1977	7	6	0	No Change	<95%
1977-1978	11	4	1	Up	98%
1978-1979	0	19	0	Down	99%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 9

Nitrogen Dioxide in Ontario 1974-1979

(Unit: parts per million - ppm)

Year	No. of Stations*	Network Average	Percentiles 10	25	50	75	90	No. of Stations	24-Hour Criterion % Stations Meeting	24-Hour Criterion Total Exceedences	1-Hour Criterion % Stations Meeting	1-Hour Criterion Total Exceedences
1974	4	.032	(.026	minimum)		(.044	maximum)	6	83	5	83	13
1975	6	.029	(.021	minimum)		(.044	maximum)	16	88	3	69	19
1976	14	.027	.008	.017	.027	.032	.038	19	100	0	100	0
1977	16	.031	.013	.020	.028	.039	.042	22	82	10	91	13
1978	18	.028	.012	.018	.031	.035	.038	24	88	5	92	2
1979	22	.024	.010	.013	.026	.030	.034	25	96	1	96	1

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1974-1975	1	2	1	No Change	Test Not Applicable
1975-1976	4	2	0	No Change	95%
1976-1977	6	2	4	Up	95%
1977-1978	2	9	3	Down	95%
1978-1979	4	13	0	Down	95%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 10

Nitric Oxide in Ontario 1975-1979

(Unit: parts per million - ppm)

Year	No. of Stations	Network Average	Percentiles 10	25	50	75	90
1975	2	.122	(.033	minimum)		(.211	maximum)
1976	11	.045	.001	.010	.025	.033	.076
1977	13	.048	.010	.017	.026	.032	.078
1978	15	.043	.005	.008	.027	.049	.069
1979	20	.030	.003	.017	.021	.034	.059

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1975-1976	0	2	0	No Change	Test Not Applicable
1976-1977	4	4	1	No Change	< 95%
1976-1977	1	10	0	Down	98%
1978-1979	4	10	0	No Change	< 95%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 11

Nitrogen Oxides in Ontario 1974-1979
(Unit: parts per million - ppm)

Year	No. of Stations*	Network Average	Percentile 10	25	50	75	90
1974	4	.032	(.026	minimum)		(.044	maximum)
1975	7	.028	(.019	minimum)		(.044	maximum)
1976	15	.027	.010	.020	.027	.034	.040
1977	17	.031	.017	.022	.032	.039	.045
1978	18	.028	.014	.020	.031	.035	.040
1979	22	.024	.011	.019	.026	.030	.034

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1974-1975	1	2	1	No Change	Test Not Applicable
1975-1976	5	2	0	No Change	<95%
1976-1977	7	2	4	Up	95%
1977-1978	2	10	3	Down	95%
1978-1979	4	13	0	Down	95%

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 12

Total Reduced Sulphur in Ontario 1975-1979

(Unit: parts per billion - ppb)

Year	No. of Stations*	Network Average	Network Minimum	Network Maximum
1975	3	1.0	0.0	1.9
1976	5	3.4	0.6	12.8
1977	8	3.2	0.0	15.4
1978	8	4.2	0.0	16.1
1979	6	3.6	0.5	10.2

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1974-1975	1	0	0	No Change	Test Not Applicable
1975-1976	0	2	0	No Change	Test Not Applicable
1976-1977	3	1	1	No Change	Test Not Applicable
1977-1978	5	0	1	No Change	<95%
1978-1979	2	2	0	No Change	Test Not Applicable

*Stations with sufficient number of samples (6570) to determine valid annual mean.

TABLE 13

Particulate Lead in Ontario 1971-1979

(Unit: micrograms per cubic meter - ug/m^3)

Year	No. of Stations*	Network Average	Percentile 10	25	50	75	90	No. of Stations	% Stations Meeting 24-hour Criterion	Total Exceedences 24-hour Criterion	Lead Consumed in Gasoline-10^9g
1971	27	1.0	.3	.5	.8	1.0	1.3	85	85	43	1.95
1972	20	1.8	.3	.6	.8	1.3	3.7	27	81	60	2.14
1973	26	1.4	.4	.6	.8	1.4	1.8	45	64	174	2.24
1974	38	1.4	.2	.5	1.0	1.5	2.6	55	53	529	2.08
1975	33	1.2	.2	.5	.9	1.4	2.1	78	72	428	1.81
1976	35	1.3	.3	.4	.8	1.4	2.0	89	85	529	1.74
1977	41	0.9	.2	.3	.5	1.2	1.5	72	79	436	1.52
1978	66	0.6	.1	.3	.4	.7	1.1	92	87	360	1.33
1979	53	0.5	.1	.2	.3	.6	1.0	75	85	342	0.71

Trend Analysis

Period	Number of Stations* Increasing	Decreasing	No Change	Network Trend	Confidence Level
1971-1972	0	8	1	Down	99%
1972-1973	4	5	9	No Change	<95%
1973-1974	1	15	1	Down	99%
1974-1975	1	22	5	Down	99%
1975-1976	10	12	9	No Change	<95%
1976-1977	2	22	8	Down	99%
1977-1978	4	21	11	Down	99%
1978-1979	1	34	9	Down	99%

*Stations with sufficient number of samples to meet the following criteria for determining valid annual mean: more than 20 samples per year with at least 4 samples per season.

TABLE 14

ONTARIO'S AIR POLLUTION INDEX

Date Started:			
	TORONTO	MARCH 23, 1979	
	HAMILTON	JUNE 15, 1970	
	SUDBURY	JANUARY 16, 1971	
	WINDSOR	MARCH 19, 1971	
	HAPPY VALLEY	MAY 13, 1971	(Closed Jan. 1975)
	WELLAND	JANUARY 1, 1974	(Closed Oct. 1978)
	NIAGARA FALLS	NOVEMBER 1, 1974	
	CONISTON	FEBRUARY 18, 1975	
	NEW SUDBURY	MARCH 1, 1976	
	SARNIA	DECEMBER 1, 1977	
	ST. CATHARINES	SEPTEMBER 14, 1979	

YEAR	CITY	NUMBER OF OCCASIONS 32	50	MAXIMUM INDEX	DATE OF MAXIMUM
1971	TORONTO	19	1	52	APR. 13
	HAMILTON	23	NIL	48	OCT. 21
	SUDBURY	26	3	87	DEC. 11
	WINDSOR	2	NIL	33	NOV. 10
	HAPPY VALLEY	20	7	64	NOV. 21
1972	TORONTO	2	NIL	45	FEB. 13
	HAMILTON	6	NIL	41	FEB. 13
	SUDBURY	7	1	79	JUNE 12
	WINDSOR	9	1	53	JAN. 29
	HAPPY VALLEY	20	11	139	MAR. 23
1973	TORONTO	3	NIL	43	OCT. 24
	HAMILTON	2	NIL	34	FEB. 14
	SUDBURY	NIL	NIL	26	MAR. 14
	WINDSOR	7	NIL	44	FEB. 19
	HAPPY VALLEY	19	10	94	AUG. 21
1974	TORONTO	3	1	50	OCT. 29
	HAMILTON	11	NIL	44	OCT. 29
	SUDBURY	1	NIL	32	JULY 13
	WINDSOR	2	NIL	41	JAN. 7
	HAPPY VALLEY	24	13	116	APR. 23
	WELLAND	46	15	77	OCT. 6
	NIAGARA FALLS	NIL	NIL	20	NOV. 9
1975	TORONTO	2	1	62	NOV. 20
	HAMILTON	10	NIL	38	OCT. 24
	SUDBURY	NIL	NIL	30	FEB. 1
	WINDSOR	NIL	NIL	28	FEB. 11
	WELLAND	NIL	NIL	23	JAN. 24
	NIAGARA FALLS	NIL	NIL	21	NOV. 24
	CONISTON	NIL	NIL	30	MAY 13

ONTARIO'S AIR POLLUTION INDEX

YEAR	CITY	NUMBER OF OCCASIONS 32	50	MAXIMUM INDEX	DATE OF MAXIMUM
1976	TORONTO	1	NIL	33	OCT. 3
	HAMILTON	8	NIL	41	DEC. 16
	SUDBURY	NIL	NIL	28	JUNE 6
	WINDSOR	1	NIL	34	DEC. 16
	WELLAND	NIL	NIL	24	DEC. 16
	NIAGARA FALLS	NIL	NIL	25	FEB. 21
	CONISTON	NIL	NIL	29	SEPT. 16
	NEW SUDBURY	NIL	NIL	29	APR. 2,3,& JUNE 20
1977	TORONTO	4	NIL	36	JAN. 15
	HAMILTON	10	NIL	44	MAR. 12
	SUDBURY	NIL	NIL	24	JUNE 11
	WINDSOR (12008)	1	NIL	33	APR. 19
	WELLAND	NIL	NIL	22	JAN. 24,25
	NIAGARA FALLS	NIL	NIL	28	FEB. 21
	CONISTON	NIL	NIL	25	APR. 25
	WINDSOR (12016)	NIL	NIL	29	APR. 19
	NEW SUDBURY	1	NIL	39	JUNE 11
	SARNIA	NIL	NIL	15	DEC. 13
1978	TORONTO	2	NIL	45	NOV. 5
	HAMILTON	7	NIL	43	NOV. 4
	SUDBURY	NIL	NIL	31	JAN. 22
	WINDSOR (12008)	1	NIL	33	APR. 19
	WELLAND	NIL	NIL	24	MAR. 15
	NIAGARA FALLS	NIL	NIL	23	NOV. 4, MAR. 11
	CONISTON	3	NIL	34	FEB. 7
	WINDSOR (12016)	NIL	NIL	28	FEB. 18
	NEW SUDBURY	1	NIL	42	FEB. 2
	SARNIA	3	NIL	41	JAN. 24
1979	TORONTO	2	NIL	35	OCT. 18
	HAMILTON	24	1	55	DEC. 22
	SUDBURY	NIL	NIL	18	JULY 7
	WINDSOR (12008)	NIL	NIL	31	FEB. 20
	NIAGARA FALLS	NIL	NIL	27	FEB. 21
	CONISTON	NIL	NIL	31	FEB. 14
	WINDSOR (12016)	NIL	NIL	27	FEB. 21
	NEW SUDBURY	NIL	NIL	28	FEB. 14
	SARNIA	2	NIL	43	FEB. 20
	ST. CATHARINES	NIL	NIL	29	NOV. 6

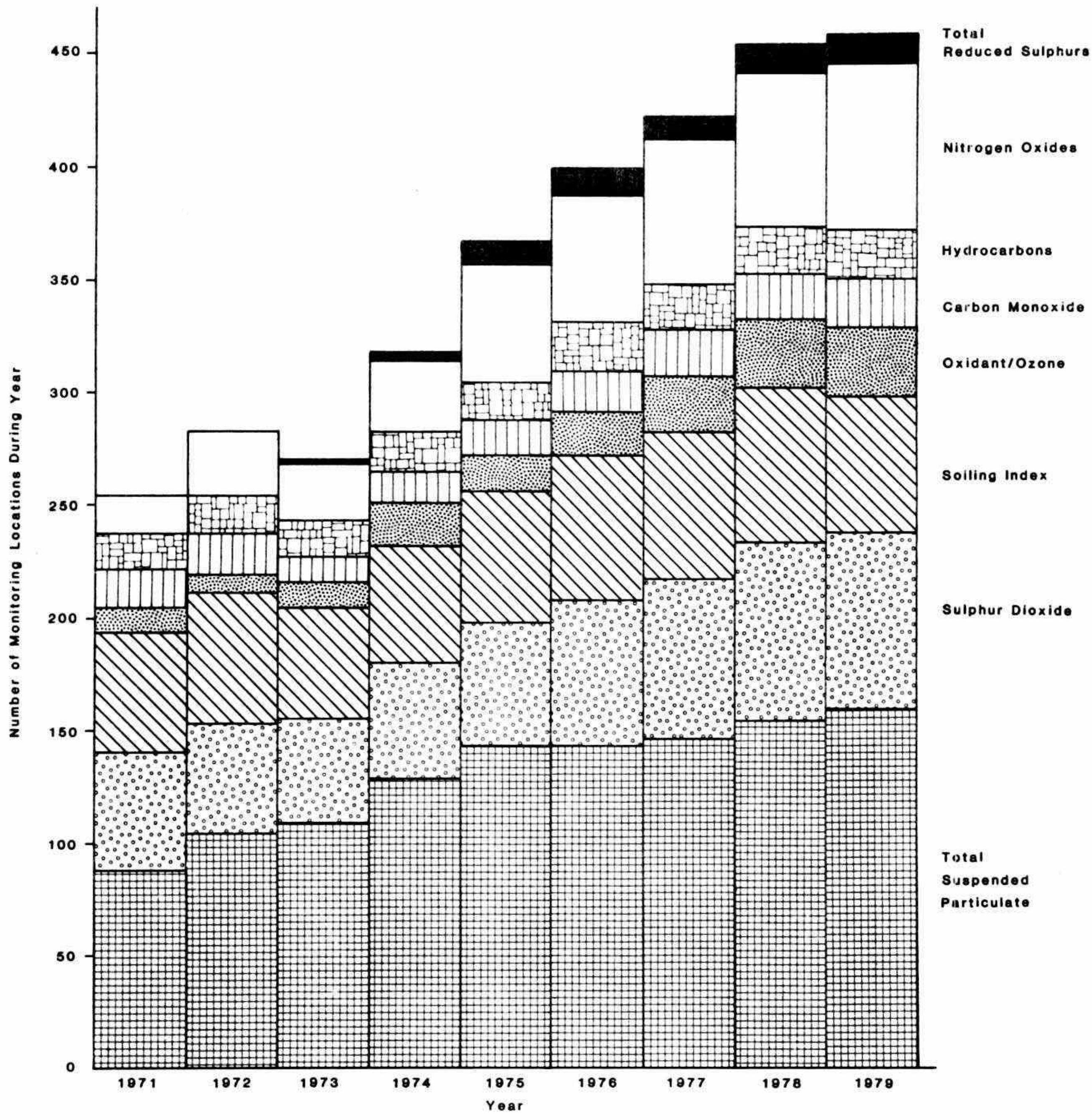

Figure 1 Ontario Air Quality Monitoring Network 1971-1979

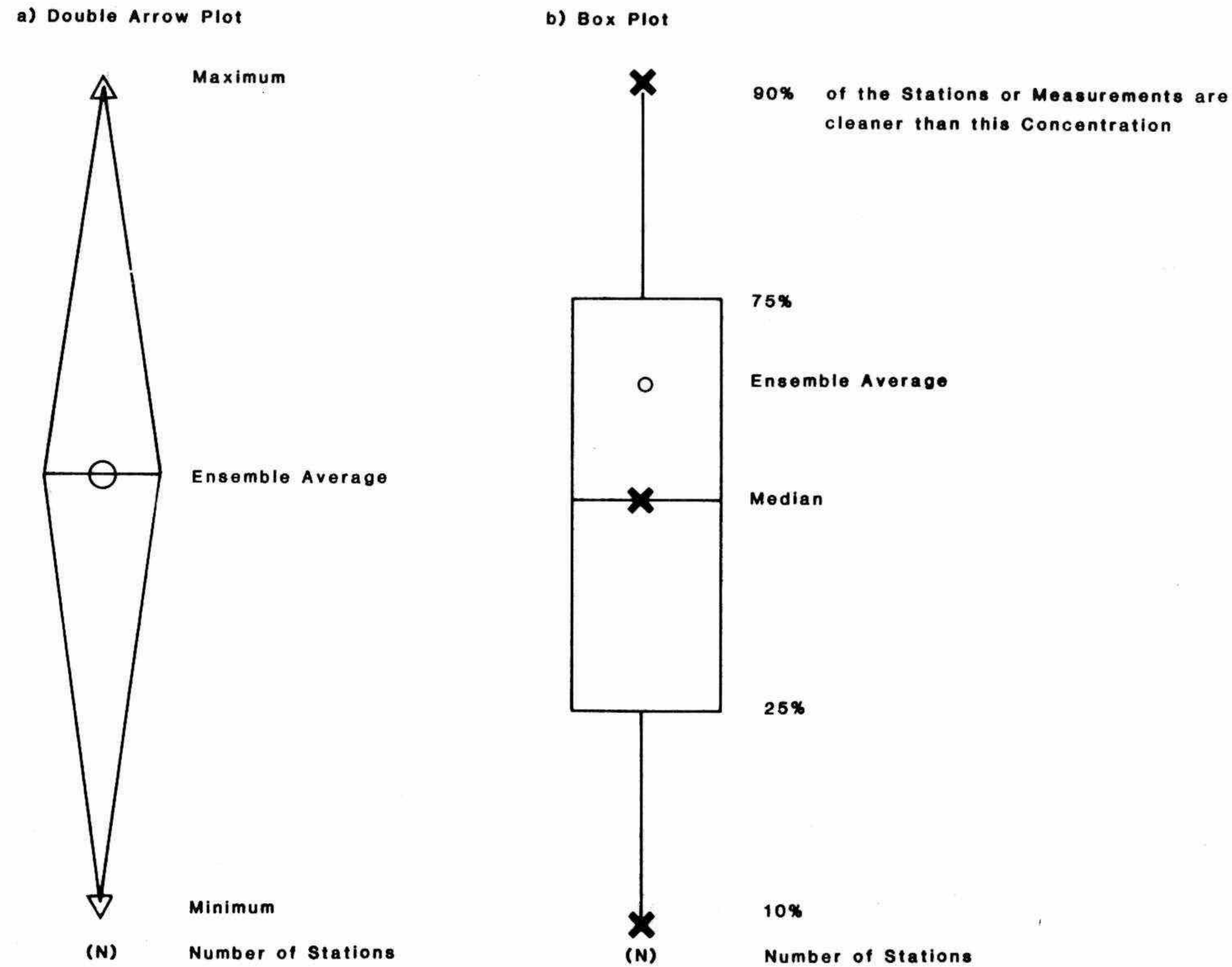

Figure 2 Plotting Conventions

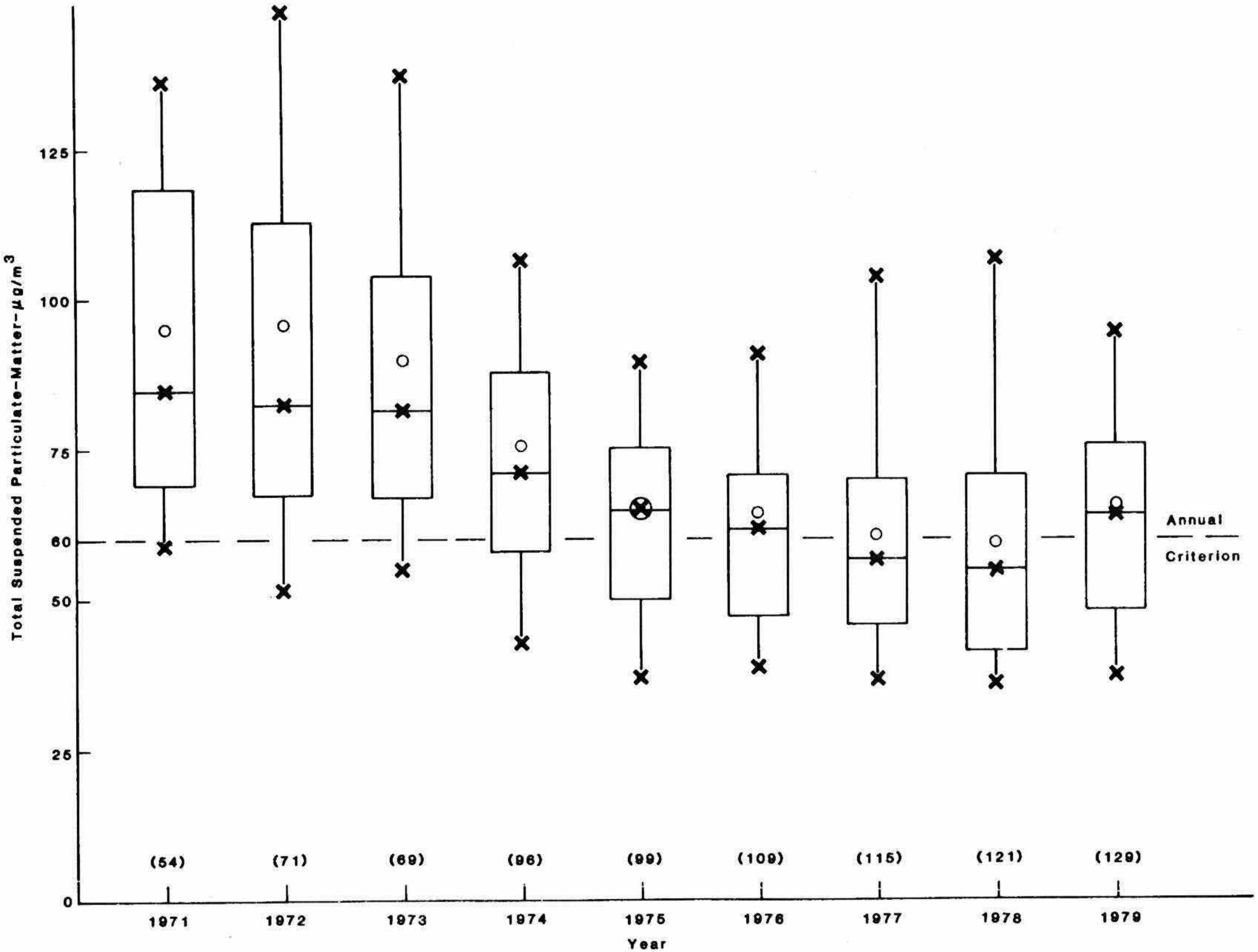

Figure 3 Trend of Total Suspended Particulate Matter in Ontario 1971–1979

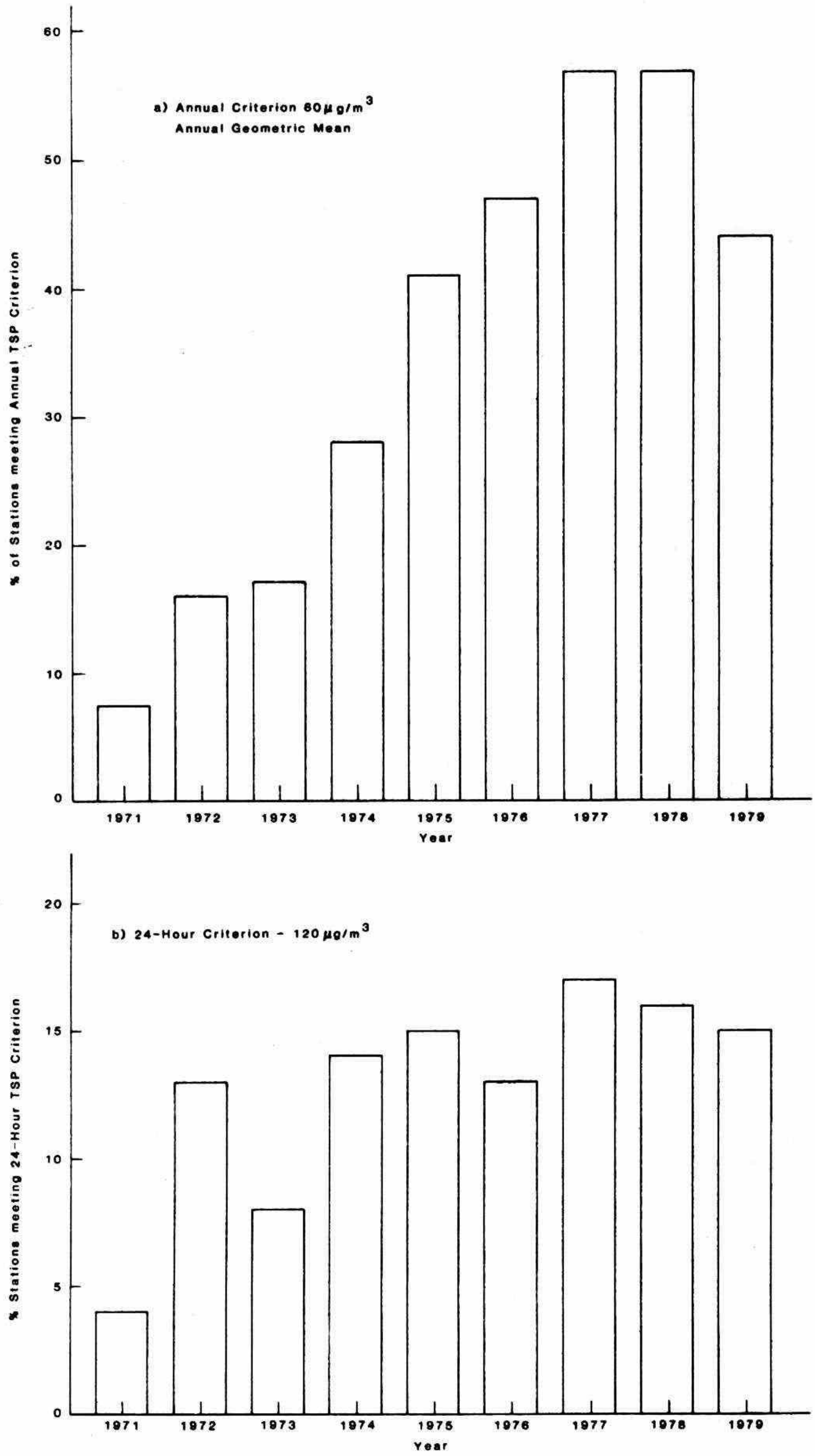

Figure 4 Percentage of Stations Meeting Criteria for Total Suspended Particulate 1971-1979

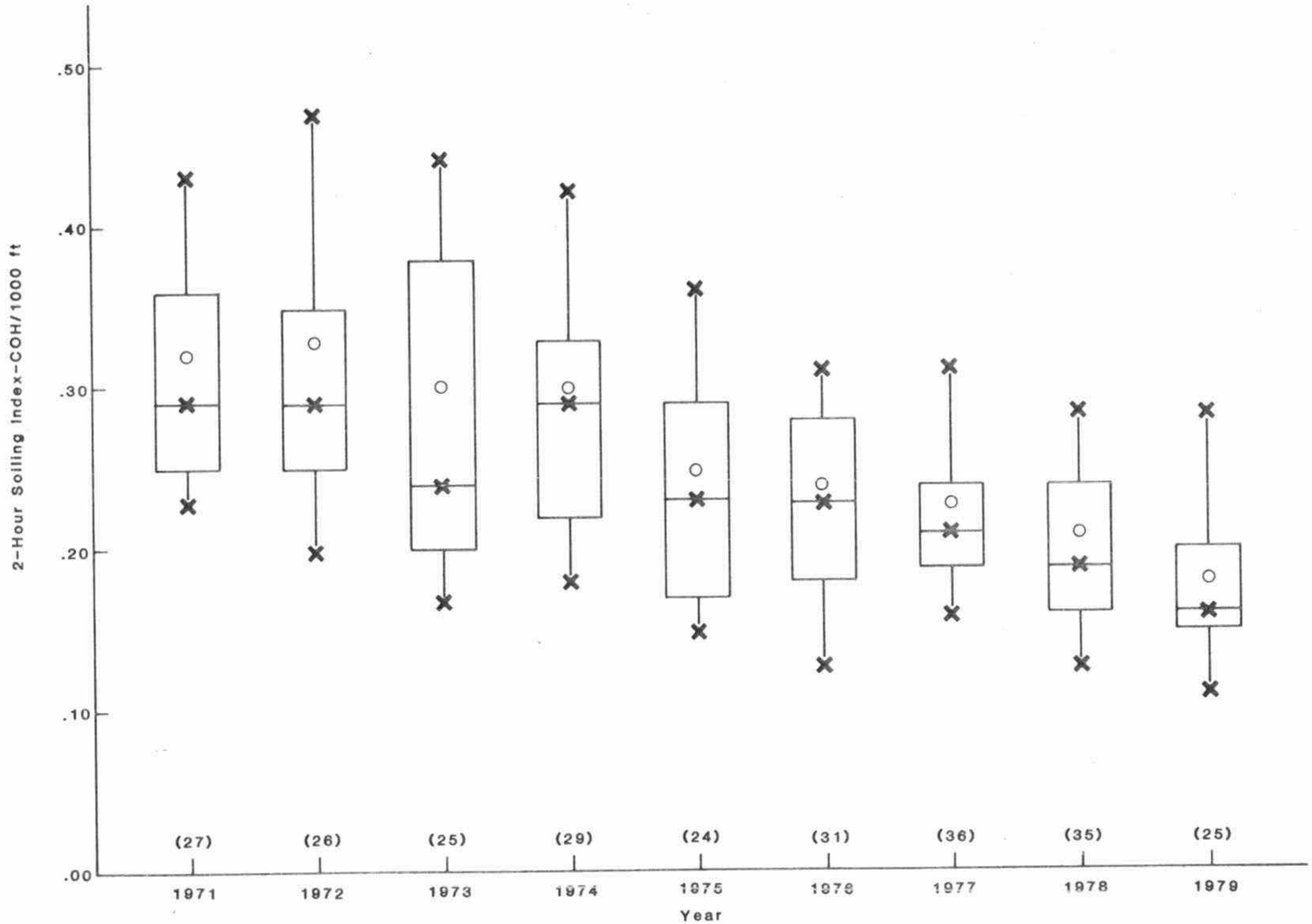

Figure 5 Trend of 2-Hour Soiling Index in Ontario 1971-1979

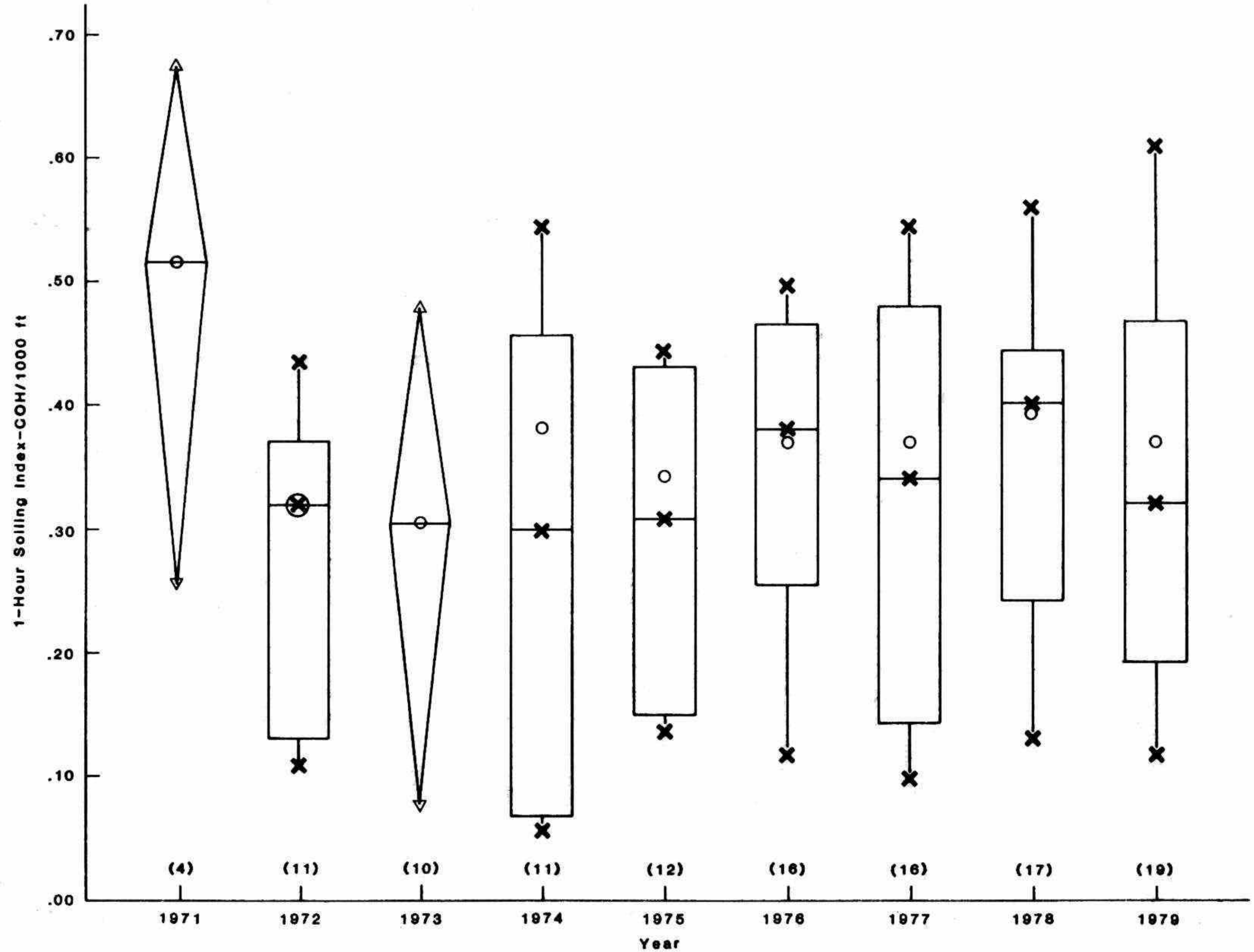

Figure 6 Trend of 1-Hour Soiling Index in Ontario 1971-1979

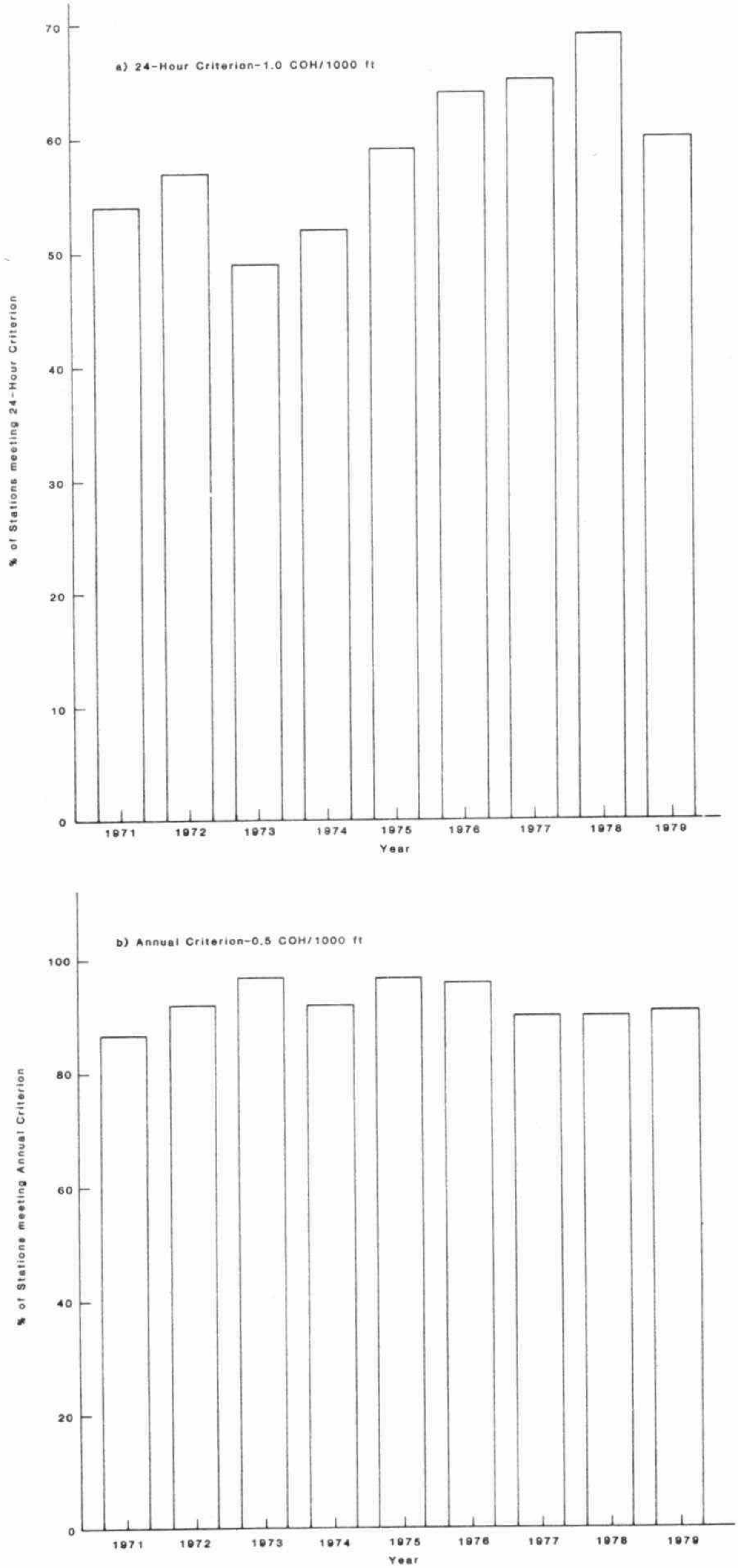

Figure 7 Percentage of Stations Meeting Soiling Index Criteria 1971-1979

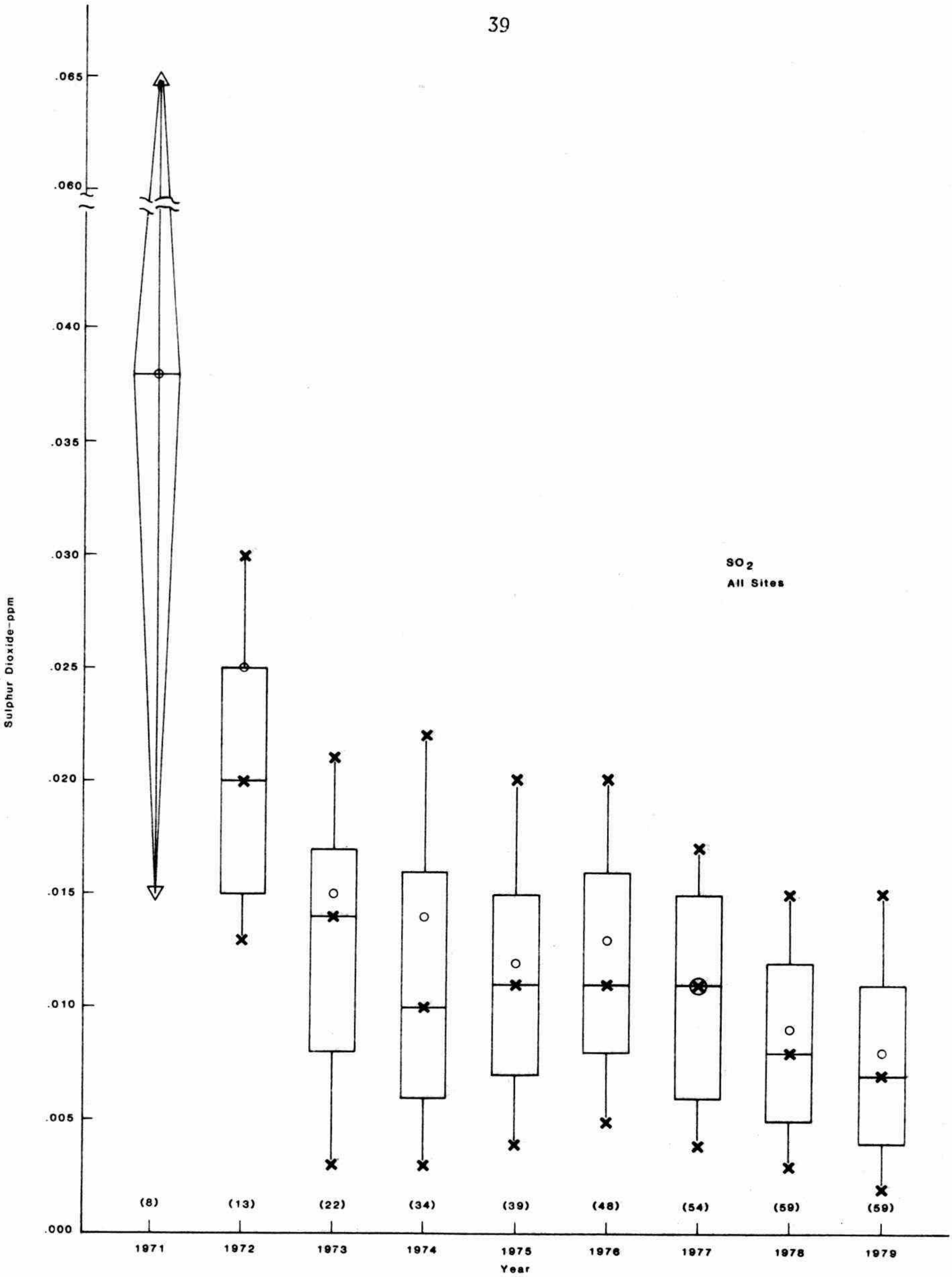

Figure 8 Trend of Sulphur Dioxide in Ontario 1971-1979

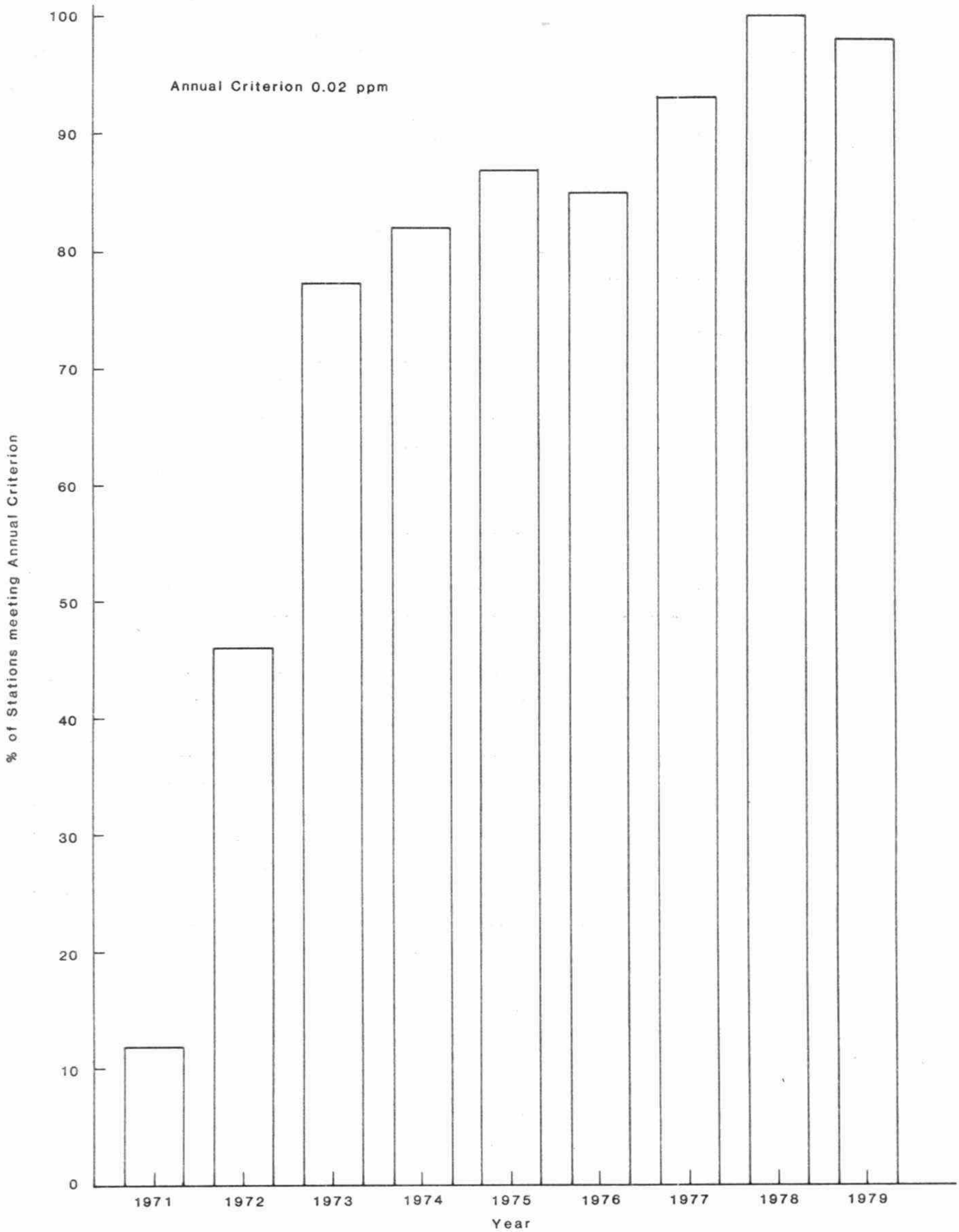

Figure 9a: Percentage of Stations Meeting Annual Sulphur Dioxide Criterion 1971–1979

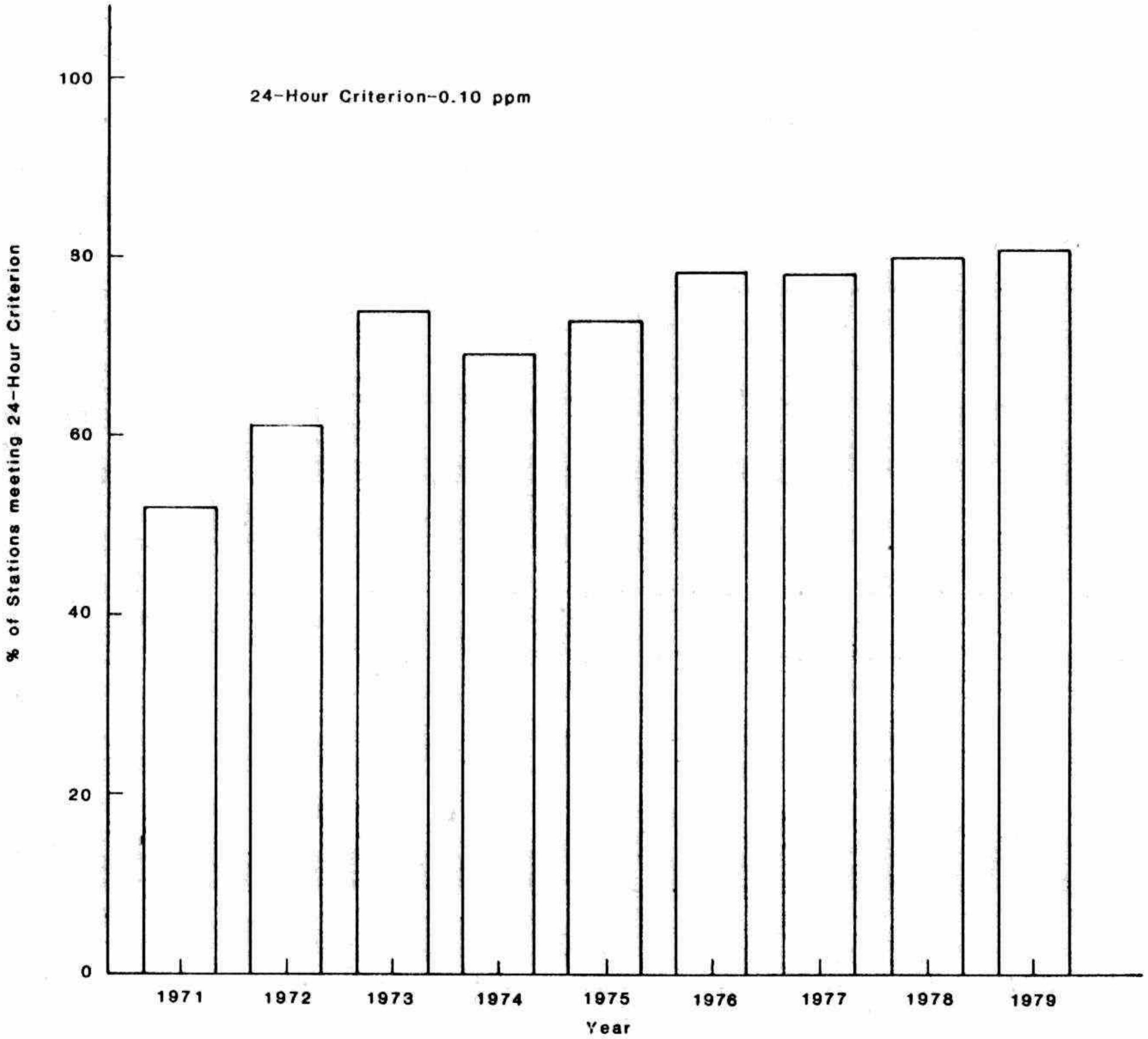

Figure 9b: Percentage of Stations Meeting 24-Hour Sulphur Dioxide Criterion 1971-1979

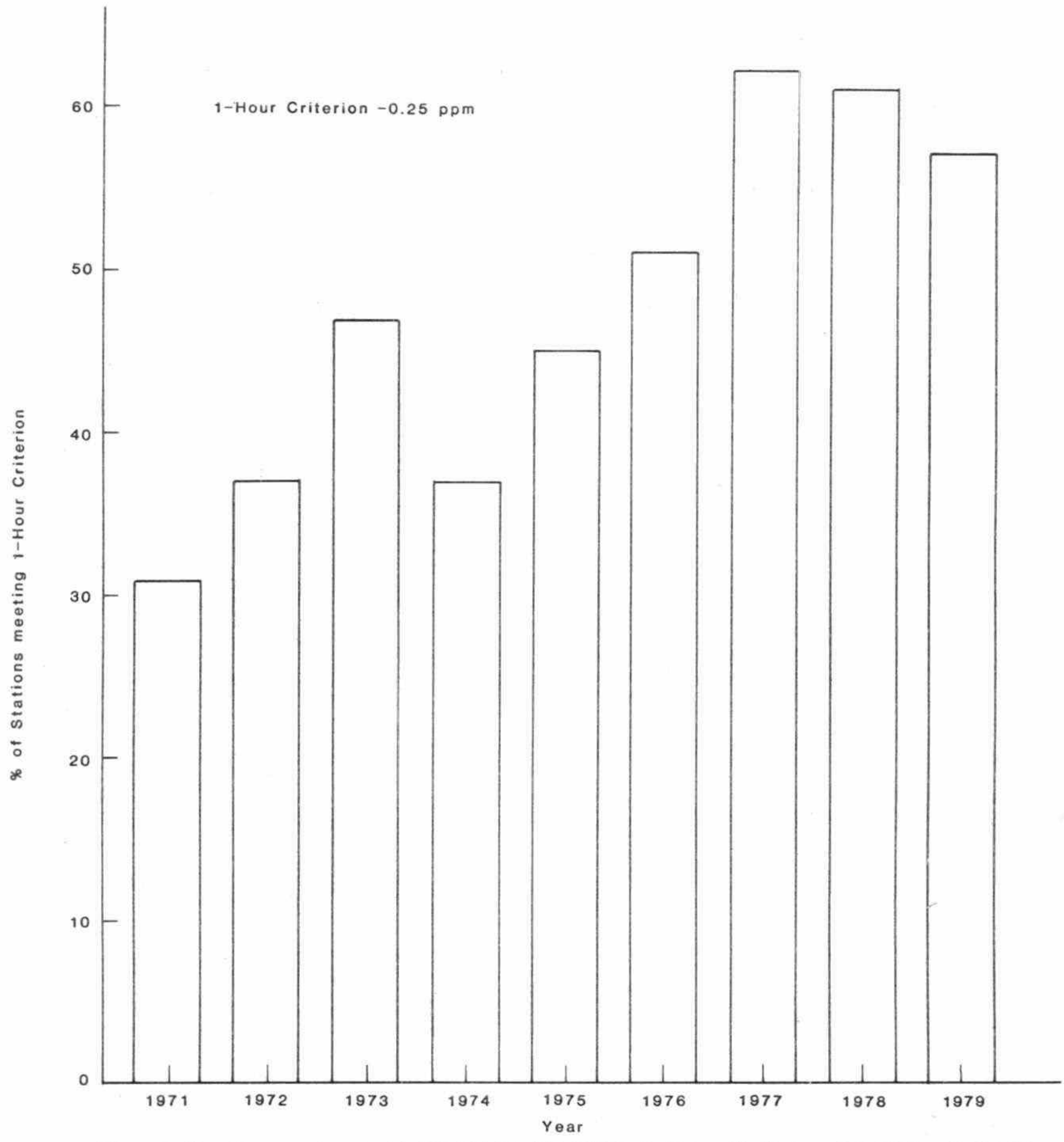

Figure 9c: Percentage of Stations Meeting 1-Hour Sulphur Dioxide Criterion 1971-1979

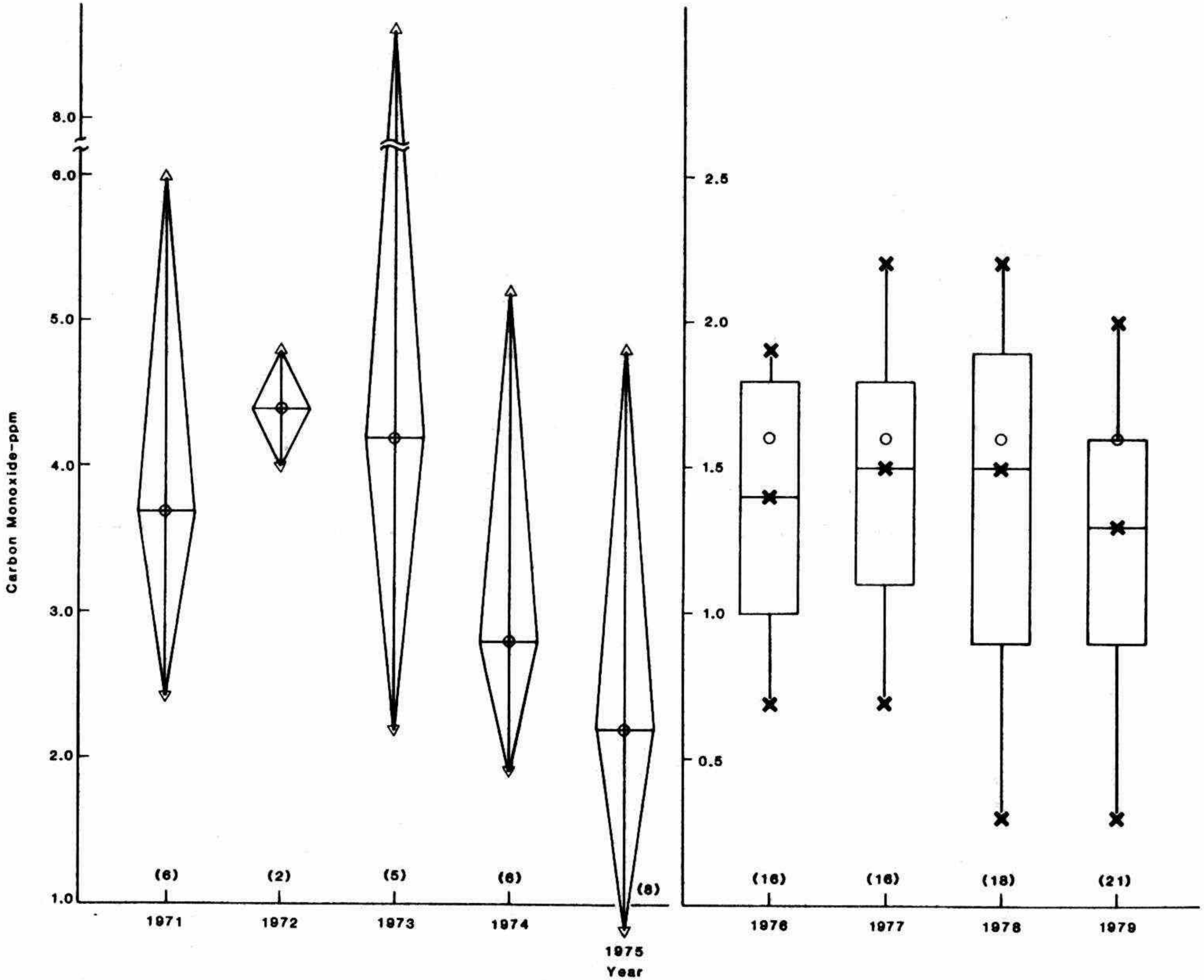

Figure 10 Trend of Carbon Monoxide in Ontario 1971-1979

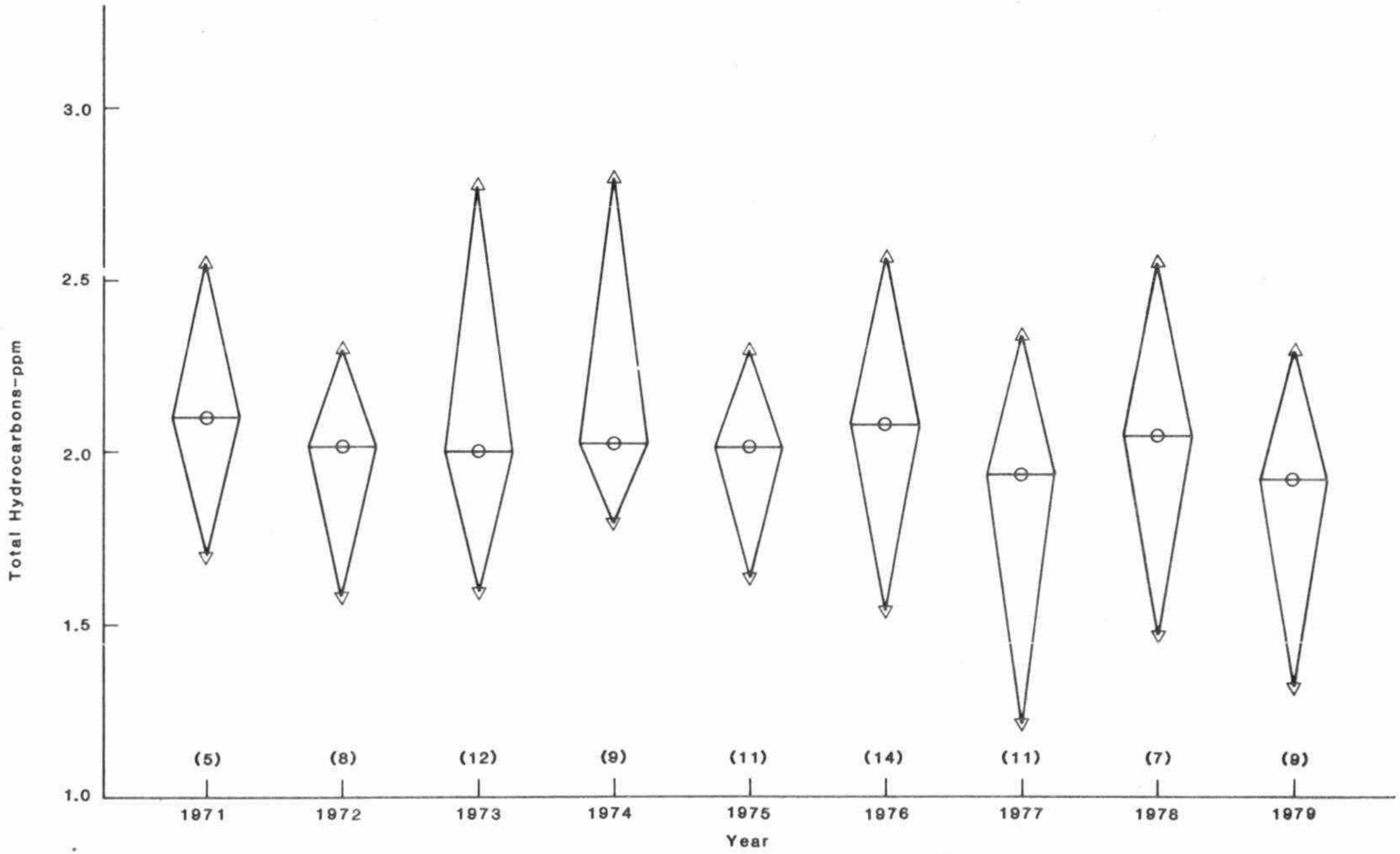

Figure 11 Trend of Total Hydrocarbons in Ontario 1971-1979

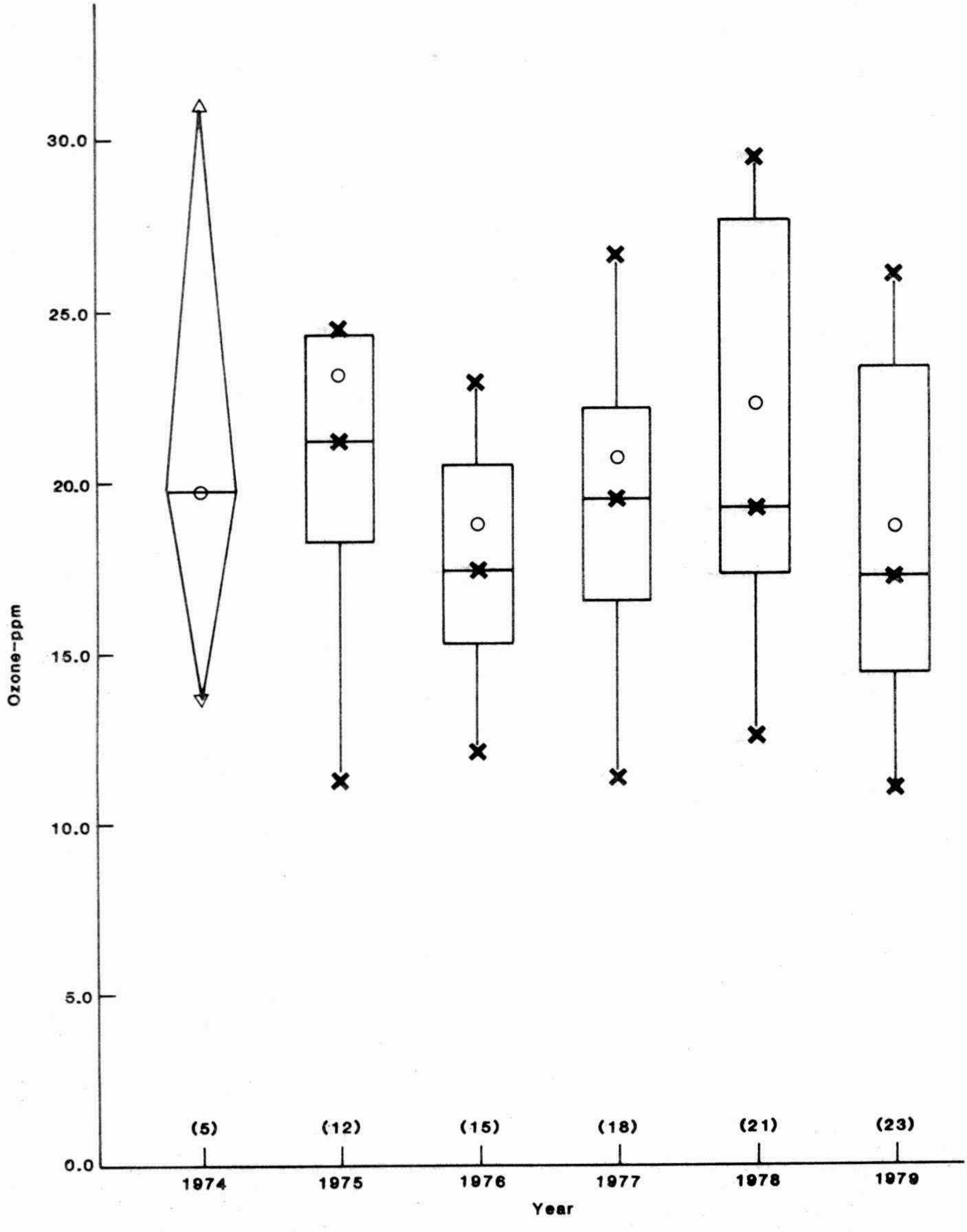

Figure 12 Trend of Ozone in Ontario 1974-1979

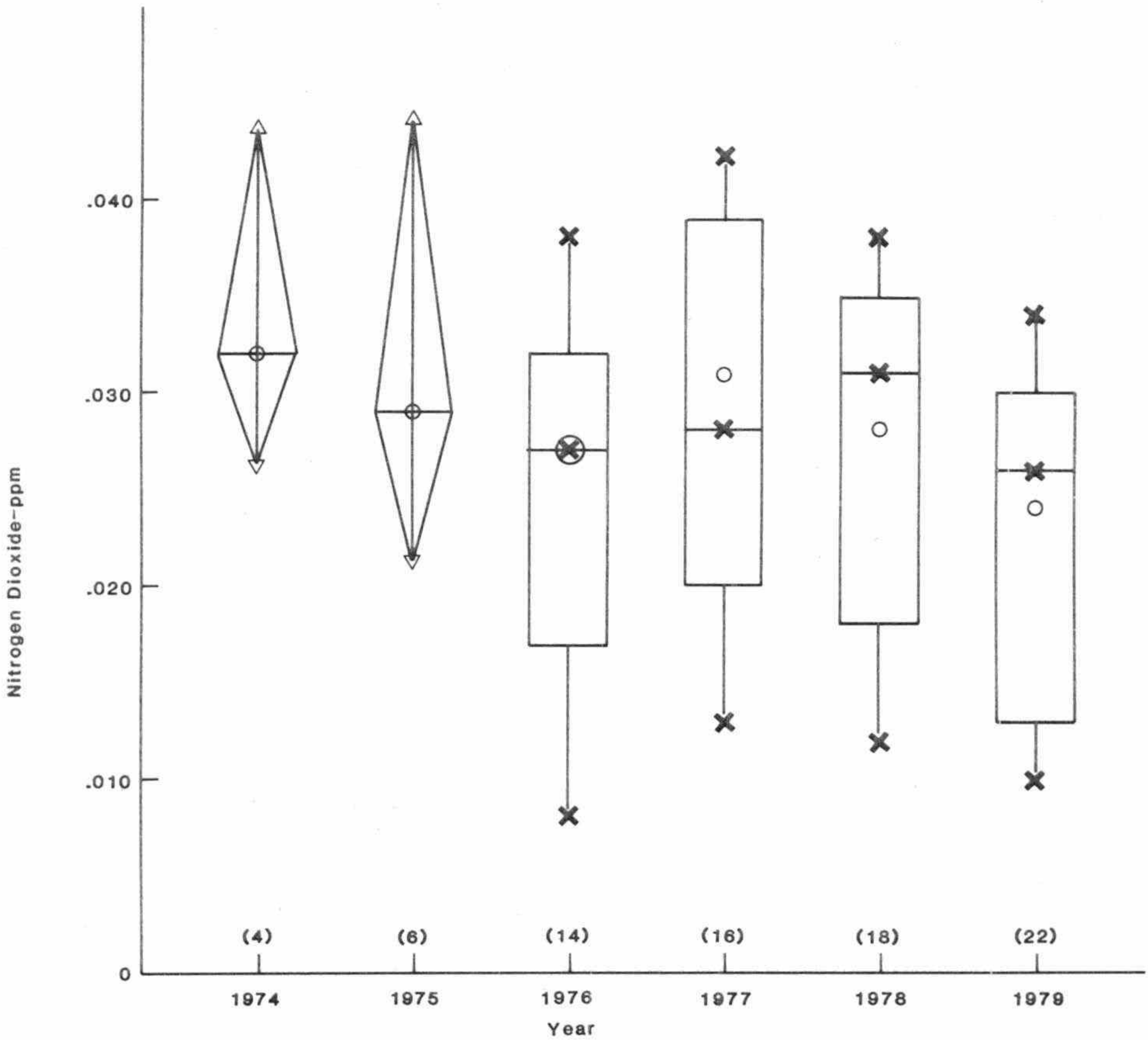

Figure 13 Trend of Nitrogen Dioxide in Ontario 1974-1979

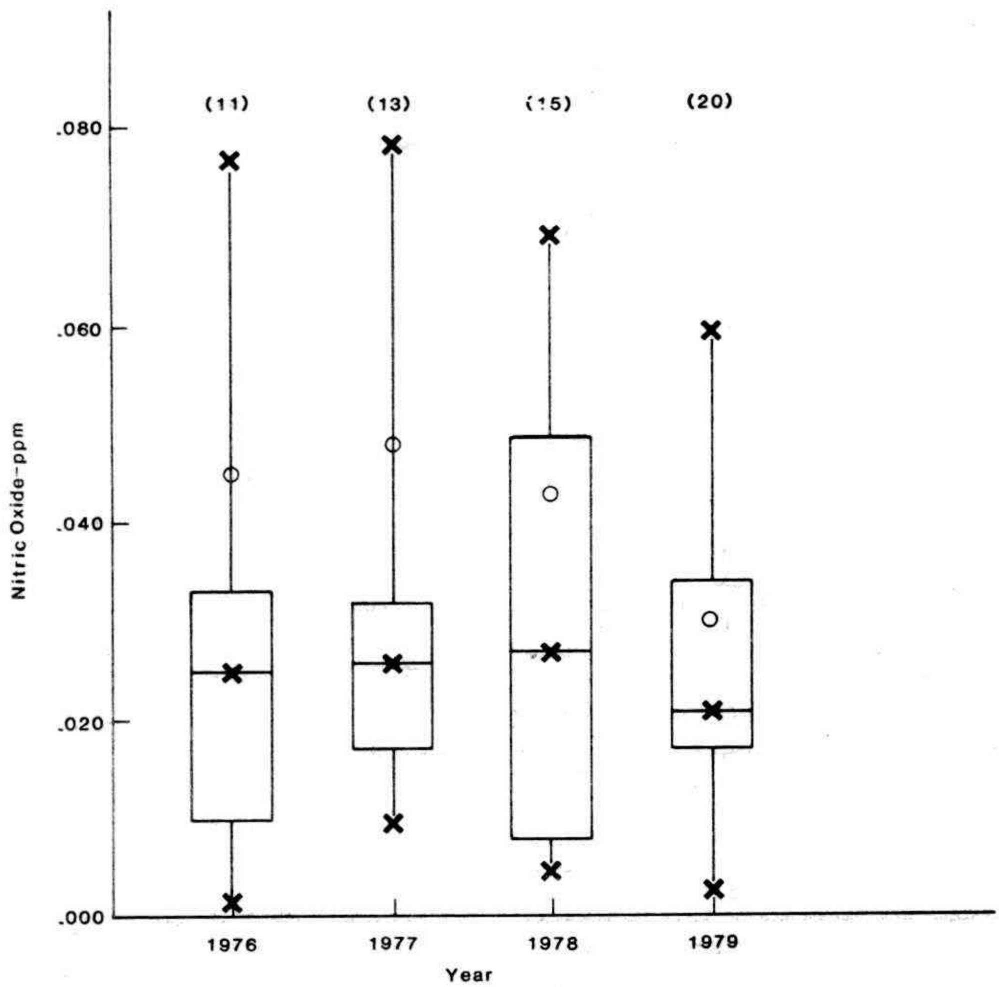

Figure 14 Trend of Nitric Oxide in Ontario 1976-1979

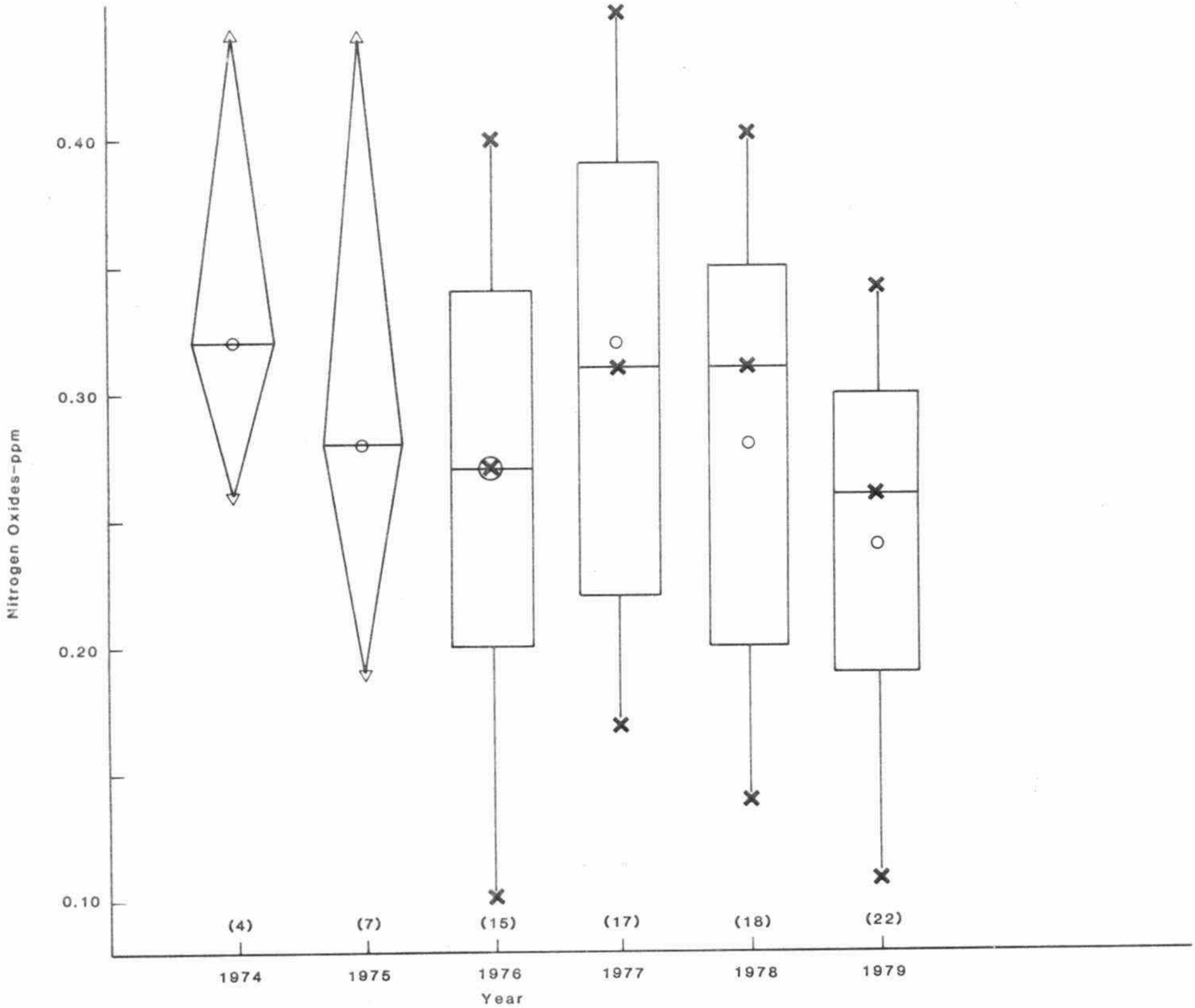

Figure 15 Trend of Nitrogen Oxides in Ontario 1974-1979

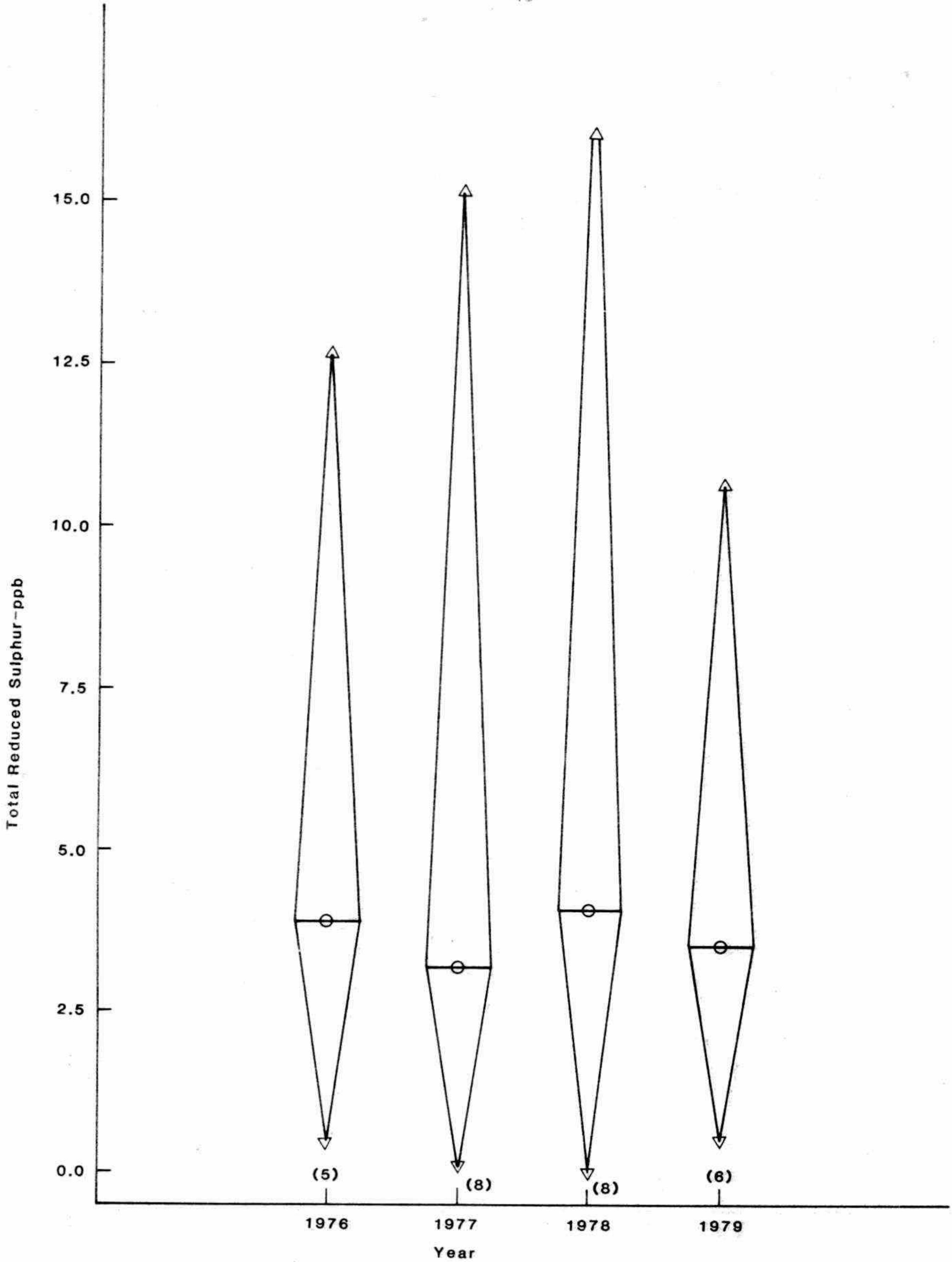

Figure 16 Trend of Total Reduced Sulphur in Ontario 1976-1979

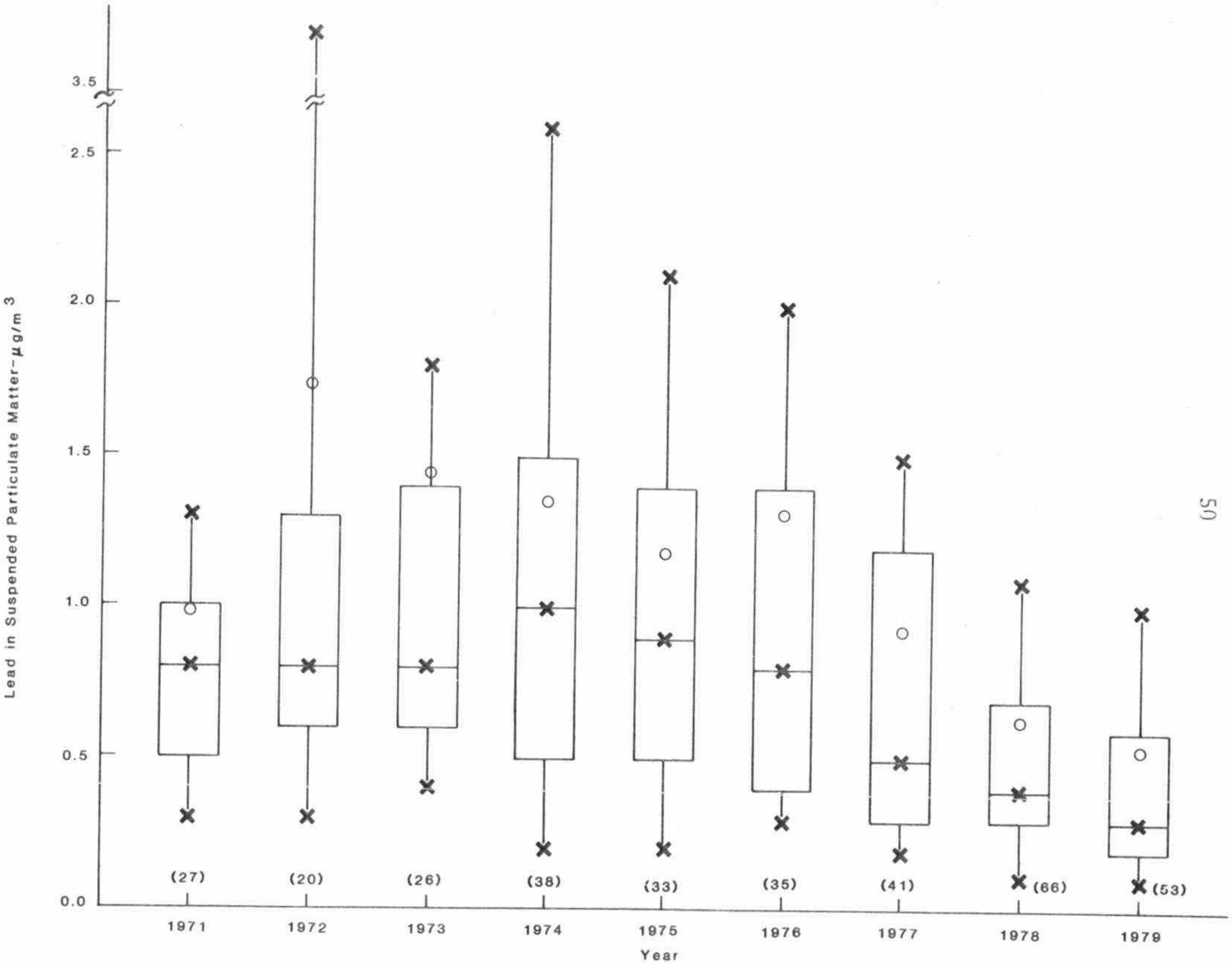

Figure 17 Trend of Lead in Suspended Particulate Matter in Ontario 1971-1979

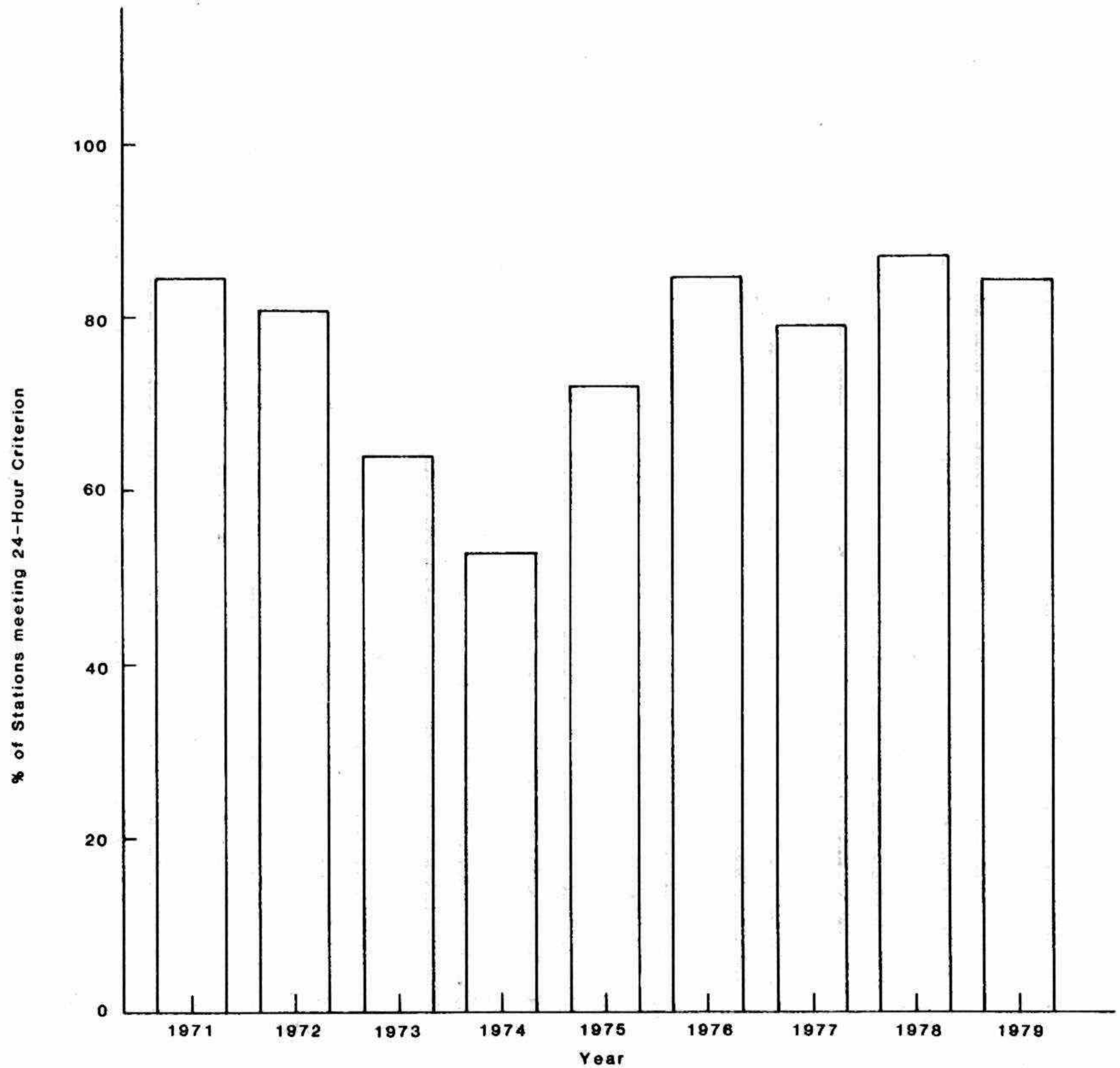

Figure 18 Percentage of Stations Meeting Particulate Lead Criterion 1971-1979

APPENDIX A

The Wilcoxon Matched-Pairs, Signed-Ranks Test

The Wilcoxon Matched-Paris, Signed-Ranks test (hereafter referred to as the Wilcoxon test) is a non-parametric test which takes into account the magnitude of pair differences as well as their sign. Non-parametic tests are tests applied to populations having an unknown distribution or a specified distribution with an infinite number of unknown parameters. Such tests may be applied to data with a nominal (qualitative) scale of measurements, an ordinal scale (ranked) of measurements, or an interval of ratio scale of measurements.

The Wilcoxon test is a test of high efficiency. The efficiency of a statistical test is based upon the number of samples required for that test as compared to the number of samples required for a different test under similar conditions. (In comparison to its parametric equivalent, the paired - Student's test, the minimum efficiency of the Wilcoxon test is 0.864).

The Wilcoxon test is a test of high power. The power of a statistical test is based upon the probability of rejecting a false null hypothesis. Using the Wilcoxon test, it is highly probable that a false null hypothesis will be rejected. Similarly, the probability of accepting a false null hypothesis is small.

The Wilcoxon test is applied in the following manner. N data points from populations X and Y are matched and the difference between the pairs computed. The non-zero differences are than ranked without regard to sign from the smallest (Rank 1) upward to n where n equal N minus the number of pairs with zero differences. Ties are each assigned a value equal to the average of the ranks the r observations would have had if they were ranked, in order, e.g., if the 2, 3, 4, and 5 rankings are taken by 4 observations of equal magnitude x, each x value is assigned the rank number 3.5. The rankings are then assigned the sign of the difference to which they correspond. The like-signed ranks are summed, and the lesser of these two sums becomes the test statistic T.

The null hypothesis is formulated to state that there is no difference between the two sets of data. This hypothesis is tested at the α significance level using T. If T is less than the critical value for a two-tailed test obtained from a table of critical values for the Wilcoxon test, then it can be said that there is a statistically significant difference between the data sets at the $(1-\alpha)$ % confidence level.

Reference: Conover, W. J., 1971: Practical Non-parametric Statistic John Wiley and Sons, Inc., Toronto. p 203-215.